# Next stop Mars

MARS HAS THE MOST extraordinary power to fuel the imagination. From Jules Verne and his *War of the Worlds*, to popular films like *Total Recall* and, yes, even *Mars Attacks*, the Red Planet has inspired some out-of-this-world drama. Yet in the past year the quest for hard facts about Mars has eclipsed even the best science fiction.

It all began last year, when researchers announced that Mars may once have supported life, and that the evidence—a meteorite chipped off Mars—landed on Earth some 13 000 years ago. In July, Pathfinder bounced into a dried-up flood plain and let loose a rover. The event created a frenzy in the media, and tens of millions of people logged onto NASA Web sites to follow events. Since then, Pathfinder and its rover have been busy. In "Postcards from another planet" (p 38) you can see some of the best images and data these robots have sent back.

There is more to come. Global Surveyor grazed the Martian atmosphere last week. And NASA has promised to send two spacecraft to Mars every 18 months from now on. A key question that planetary scientists hope to answer is why Mars turned from a warm, wet paradise into a barren, frozen desert, and whether a similar fate could be in store for Earth. "Death of a watery world" (p 34) explores their strategy for doing this.

These craft will also pave the way for human interplanetary flight. Whether anyone actually travels to Mars is still wide open. NASA is uncommitted. But it is designing its missions to study problems that must be solved before anyone gets to go.

Unlike robots, people need oxygen, heat, food and a way to get home. That will make a human mission hugely expensive. The cheapest round trip is estimated at $20 billion, compared with the $150 million or so each for Pathfinder and Global Surveyor. And there are plenty of critics who ask what humans can do on Mars that robots can't.

Then there are the risks. Little is known about the effects on humans of interplanetary travel. It is clear from "2011: A Mars odyssey" (p 28), that the journey to Mars would leave astronauts seriously weakened. Perhaps one of Pathfinder's successors would give a human crew weakened by months in space a real run for their money.

The human desire to explore and conquer is not going to go away. Early next century, a select group of scientists, technologists and politicians will have to decide whether to ask a human crew to suit up, ready for a mission to Mars. They could play safe, and stick with robots. Or they might take a giant, imaginative leap for mankind . . .

# A Mars odyssey

**Explorers setting off for the Red Planet must survive and stay healthy for two years or more in the harsh conditions of space. *Robert Taylor* follows their fate**

***July 20, 2011, Kennedy Space Center, Florida. Explorer I blasted off for Mars at dawn today. The Explorer, with its crew of three men and three women from four nations, will land on the Red Planet in six months, and head home only after an 18-month exploration of its surface. "We have complete confidence in our equipment and our ground support team," said mission commander Nathaniel Ramirez. "Now it's up to us..."***

If NASA had a nickel for every science fantasy about humans exploring Mars, it could send the entire US astronaut corps to the Red Planet, first class. But science fact may catch up with science fiction sooner than you think. People could walk on Mars within 15 years, say space scientists in the US and Russia who are busy sketching out plans in anticipation of getting the go-ahead. "Sending people to Mars is a great challenge, but not an impossible one," says Lewis Peach, who oversees planning of NASA's "reference mission" to Mars at the Office of Space Flight in Washington DC.

There is, however, one potential trouble spot: the "people" part. The astronauts will be the most complex and least understood system on a Mars mission, and keeping them safe, warm, and happy for the duration will be a tricky technological feat.

Tricky. But with a little forward planning, doable.

***October 4, 2011, Korolyov, Russia. An intense solar flare forced the crew of Explorer I to take refuge in their on-board radiation shelter, flight controllers reported today. The crew is in no immediate danger, but must remain in the closet-sized shelter until radiation levels abate, which may be several days. "I am glad that we are all good friends," said systems specialist Elisabeth Schweitzer-Maier...***

Space is a hot place. Outside the Earth's protective atmosphere and magnetic field, atomic nuclei zip along with as much as 1 gigaelectronvolt of energy. When these cosmic rays strike flesh they blow biological molecules to bits. They also generate electrons and gamma rays when they hit anything solid, be it human skin or the spacecraft. For added excitement the Sun throws out a solar flare once every year or

*Illustrations: Chris Draper*

Jusqu'en 2005, les sondes vont continuer de tourner autour de Mars pour achever l'inventaire de la planète. Mais c'est au sol que vont se jouer les principaux défis des missions à venir.

so. These eruptions generate huge doses of high energy protons that would kill unprotected astronauts within hours.

The Mars spaceship will need shielding, shielding means more mass, and more mass means more money for more rocket. For that reason, only a small room at the heart of the ship will be heavily protected, and much of that protection will come from clever positioning of supplies. Astronauts will retreat to this "storm shelter" if a flare hits during transit. Otherwise, they will rely on the skin of their ship to block most of the routine rain of smaller particle radiation; there is no practical way to keep out heavy nuclei.

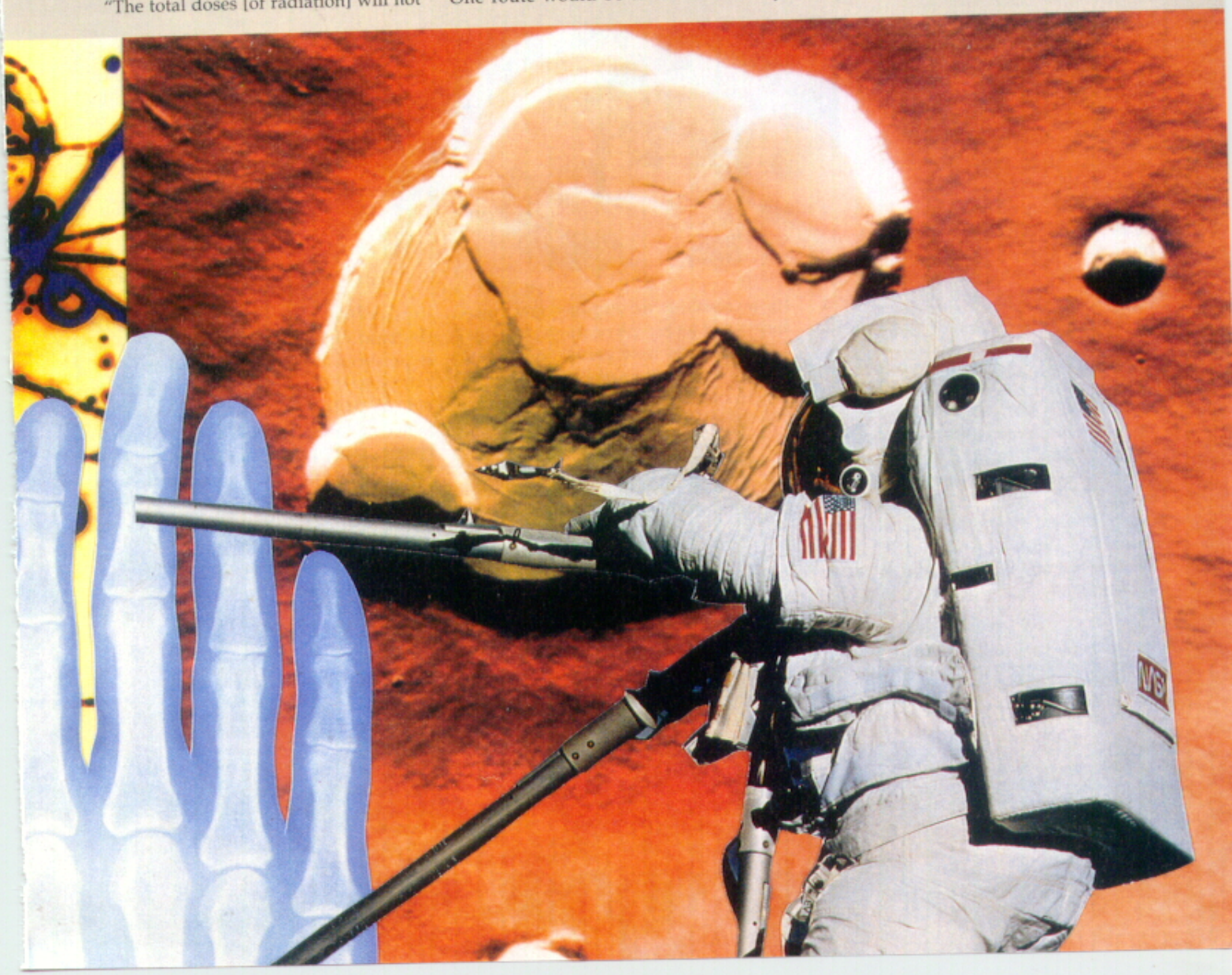
Once the crew reaches Mars, their nuking is far from over. The thin Martian atmosphere and insignificant magnetic field are poor protection, although the planet's bulk will reduce the cosmic ray dose. Sandbags thrown up on the habitat's roof would help, too.

"The total doses [of radiation] will not be negligible," says John Dicello of Johns Hopkins University in Baltimore. Dicello was on the panel of the US National Academy of Sciences (NAS) that released a report on the radiation risks of lengthy space flights late last year. Just as explorers on Earth used to take for granted the risks of snake bite, scurvy, and shipwrecks, interplanetary explorers may have to accept a higher cancer risk as part of the deal.

But how much higher? Over their whole careers, NASA astronauts, and those who will fly on the International Space Station (ISS), should be exposed to no more radiation than that estimated to increase the risk of dying from cancer by a minuscule 3 per cent, says Tracy Yang, a radiation safety officer at Johnson Space Center in Houston. Mission planners say that they will aim for a similar figure for the astronauts who travel to Mars.

Achieving that goal will not be easy. One route would be to turn down any

potential Mars explorers whose genes may predispose them to radiation-induced cancer. Some genetic profiles—certain versions of genes like *ATM* or *BRCA2*—could increase that risk. And, of course, by the time a Mars rocket is ready to go, testing for genetic susceptibility to



cancer will be down to a fine art. But using information about genetic risk is just as touchy a topic for NASA as elsewhere. According to Yang, medical information is only currently used to make astronauts aware of their risk, and not to bar them from any activity.

Then there's the problem of how to predict just how nasty cosmic radiation might be. At the moment, estimates are based on what is known about the effects on the body of gamma rays and X-rays. But the real risks from cosmic radiation could be higher or lower by as much as a factor of fifteen, says Dicello. And cancer may not be the only side effect of radiation exposure. For example, practically nothing is known about how the nervous system will withstand a three-year cosmic ray shower—it would not look good if the crew developed a mysterious dementia when they got back home.

To clarify the danger from radiation, the NAS report urged NASA to buy or rent a heavy particle accelerator, so they could find out what happens when you zap human cell cultures and animals with high energy particles. If these experiments show that the human body is less susceptible to cosmic radiation than experts have feared, the savings on shielding would be astronomical, the NAS points out.

***January 27, 2012 Johnson Space Center, Houston. After a harrowing landing, the Explorer I crew is safe in their habitat module placed on Mars two years ago. A faulty thruster pushed the ship 3 kilometres from its target site, where it overturned on a boulder-strewn plain. Only fast action by geochemical science specialist Valentina Kondekova, the one member of the crew able to walk more than a few paces in the first hour after landing, saved the mission.***

***After stabilising a leak in the emergency oxygen generator, Kondekova walked and crawled to the habitat, returning in the habitat's rover to rescue the others...***

"Use it or lose it" is nature's iron law of fitness. And when astronauts live in microgravity, they lose it in buckets. For the first few days in space, "losing it" takes its most conspicuous form—nausea and vomiting hits most space travellers, and hits them hard. But almost all astronauts get their space legs in a few days.

The long term effects of microgravity

are more insidious. Muscles and bones decay, and every physiological system that takes a cue from gravity gets subtly out of whack. For example, the heart can lose its rhythm—witness the arrhythmia suffered by Vasili Tsiblieyv this summer in the waning days of his Mir tenure.

These changes make coming down again particularly unpleasant, even dangerous—blood pressure plummets as gravity pulls your blood back down to your feet. "In the first four to six hours you can't do very much, especially in the way of picking things up," says NASA astronaut John Blaha who spent four months aboard Mir.

A Mars crew will make this transition twice. First on Mars—Martian gravity is 38 per cent that of Earth—and again on their return home. One of the problems in predicting the impact of reduced gravity is that no one knows how well Martian gravity will help preserve the astronauts' normal physiology. That, and the fact that people vary enormously in their responses to changes in gravity. Valeri Polyakov shocked everyone by climbing out of his Soyuz capsule and walking, albeit shakily, after a record 14 months in space. Polyakov—no surprise here—is confident that astronauts would adapt easily to Martian gravity.

Mars explorers won't be allowed to go to seed as they float to their destination, either. Like the residents of Mir, they will follow an exercise regimen designed to ward off the worst effects of microgravity. Marathon runners and returning Mir cosmonauts alike often have poor "orthostatic tolerance"—they cannot maintain their blood pressure while standing still for long periods, says Inessa Koslovskaya, chief of neurophysiology and countermeasures at Moscow's Institute for Biomedical Problems. Weight lifters, on the other hand, have great orthostatic tolerance, she says. So the Mir exercise programme is designed to maintain strength—the ability to sprint and to lift heavy weights (in microgravity, the ability to stretch bungee cords)—rather than aerobic endurance, which has been the main target of the exercises used by astronauts on shorter NASA space flights. The problem, says Koslovskaya, is convincing spacefarers to work out. "Cosmonauts prefer to work with their heads."

But perhaps the threat of crippling bone loss on a trip to Mars would motivate them. Most of the physiological changes

**1·5 m–100 000 years ago**

Early humans set out from Africa to explore Europe and Asia

**510 BC**

Hanno of Carthage (near modern Tunis) explores the West African coast. He returns with exotic animals and tales of creatures like gorillas

**14 000 years ago**

Hunter-gatherers take advantage of a drop in sea level to cross the Bering land bridge that connects Asia with the American continent

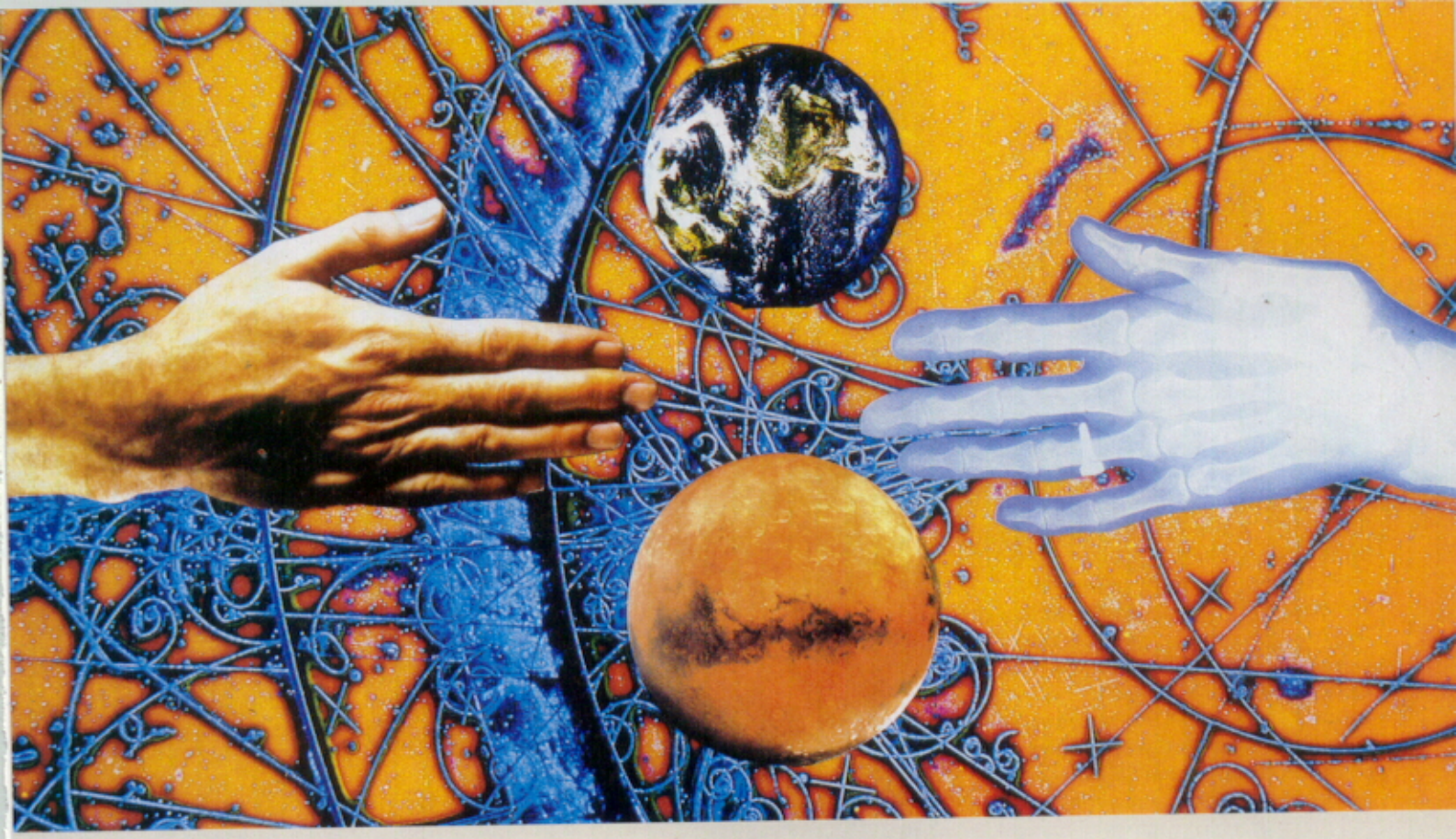
**330 BC**

Pytheus of Masilia sails from France to Ultima Thule (modern Iceland or Norway), 6 days north of Britain and 1 day short of "the end of the world". He returns with stories of a "midnight sun". No one believes him

**AD 1295**

Marco Polo returns to Venice after exploring China for 17 years. But many of the new words he learnt were Persian, not Chinese, and he seems to have missed some major landmarks like the Great Wall. Some scholars now question whether he ever made it to China. Nevertheless, his descriptions of Eastern riches inspired other explorers

*Compiled by: Nell Boyce*



measured in Mir cosmonauts stabilise at around 3 months. Bone loss, however, continues at a rate of 1 to 2 per cent per month. And so far it's not clear whether any of the countermeasures used on Mir or the US space shuttle have helped, says Adrian LeBlanc who conducts NASA-funded research into muscle and bone loss at Baylor College of Medicine in Houston. Stressing bone to the limit in combination with drug therapy may be the only way to keep bones strong, he says.

To test his theory LeBlanc is studying 30 volunteers on bed rest, in which bone loss closely mirrors that seen in space. Once a day, ten volunteers will do a few sets of exercises with as much weight as they can lift, increasing the load and number of sets as their strength increases. Ten volunteers will take alendronate, a drug used to treat osteoporosis. Ten other slug-a-beds will skip both the exercise and drugs, and serve as controls. LeBlanc is monitoring the volunteers' bone density with an X-ray scanner, and following calcium balance by analysing urine and blood serum. If neither the exercise nor the drugs work, nor both together (which is what LeBlanc will test next), "I don't know what will," he says.

Perhaps high frequency vibrations. Studies on bird, sheep, and human bones suggest that high frequency vibrations promote bone formation, although no one yet knows how. Allen Goodship at the University of London is now testing that hypothesis on Mir. The cosmonauts exercise on a resistive "stepper" similar to the ones found in gyms but with a gizmo on one footplate that whacks the user's heel when the leg is fully extended, setting off a spike of vibration in the bones; the other leg is the control.

"One cosmonaut has used it so far, for about 15 minutes per day, and he rather enjoyed it," says Goodship. What's more, the bone densities of the cosmonaut's untreated heel and shin bones fell by up to 7 per cent during the flight while the treated leg lost no bone, although the beneficial effect did not reach as high as the hip. Goodship hopes to get more cosmonauts to give his heel whacker a try.

***April 12, 2013 Johnson Space Center, Houston. Explorer pilot and biology specialist Hashiro Okazaki returned to full duty status today after a two-week "recuperation period". Okazaki broke his ankle two months ago when he tripped over a cable. In a statement released today he denied reports that he has become uncooperative and depressed. "I appreciate [the] concern, but I need only rest," he said. "Really..."***

Imagine camping out with five companions in a largish caravan. Might be fun. Now imagine that the trip lasts two years or more. And you're 100 million miles from home. And you can't go outside without elaborate preparation. And it's dusty and cold out there anyway, and

**AD 1492**

Christopher Columbus sets out to cross an ocean that's bigger than he ever imagined. Shortages of food and fresh water drive his crew close to mutiny. They finally land in the Bahamas, but until his dying day, Columbus believes he had reached the Far East

**AD 1768-71**

In search of the fabled southern continent, Terra Australis, James Cook sets out in the Endeavour, taking British astronomers along to view the transit of Venus across the Sun in 1769. He successfully combats scurvy and charts the coast of New Zealand and the eastern coast of Australia

**AD 1804-06**

Meriwether Lewis and William Clark cover 8000 miles of the uncharted American West. The team of 45 men and one woman suffers constant food shortages, capsised boats, and intestinal problems from eating boiled roots. Two men desert the expedition, one gets discharged for mutiny, and Lewis and Clark enforce discipline by flogging the others

always the same. And the food is boring. And a single mistake could cost all your lives. And communications home have a 40-minute delay between saying something and hearing a reply. And the TV reporters don't seem that interested in you any more. And one of your companions picks his teeth all the time with his fingernail. And he doesn't even say excuse me. And if he does that one more time, you're gonna pick up this spare oxygen tank and…

A trip to Mars is not for the faint of heart. The crew will be isolated, confined, with no hope of resupply or early return—the planets' orbits are such that a launch window only opens once every two years. NASA's current plan calls for a six month transit to Mars, and six months back, with perhaps an 18 month stay on Mars. Low morale or bad group dynamics—not to mention depression or other mental disorders—could be catastrophic.

But explorers have survived incredible hardships before, and could do so on Mars, says Jack Stuster, a NASA-funded researcher with ANACAPA Sciences, a company in Santa Barbara, California. Stuster's book *Bold Endeavors* explores what space flight can learn from polar exploration. Selecting the right people will be half the battle. Competition for a berth will be fierce, but the ideal candidate will not be a hyper-achieving, single seat fighter pilot, as many astronauts have been in the past. Instead, says Stuster, the perfect Mars explorer will have experience on small teams facing difficult tasks. Someone like William Shepherd, named last June as the first ISS commander. A veteran of two shuttle flights, Shepherd spent ten years in the US Navy SEALs and other elite special forces units. "An ability to subordinate one's own interests to the group's, is a core SEAL value," says Stuster. This is just the kind of right stuff a Mars explorer will need.

While people in isolated research or space stations rarely lose their heads completely, specific emotional problems crop up again and again, says Stuster. Workers often feel forgotten by the folks back home. They can develop an us-versus-them antagonism with mission control, which could lead to outright mutiny. Astronauts on the third US Skylab mission in 1974 got so irritated with ever escalating demands from the ground that they unilaterally took a day off. Stuster says that in the aftermath, the astronauts and mission controllers had "the first sensitivity session in space". The isolation can also induce lethargy, depression, or paranoia. And sparks tend to fly easily among people cooped up under harsh conditions; on two occasions a Russian crew on Mir came home earlier than planned because the cosmonauts just couldn't stand each other anymore, Stuster says.

Training for space station astronauts has begun to take into account social and psychological stresses, and includes conflict resolution techniques and training in the cultures of fellow crewmates, says Frank Hughes, director of space flight training at Johnson Space Center. There are also plans for a "crew support system" on the ISS that will include a laptop computer each, books, videos, educational programmes and provisions for private communication with home and individual counselling. Hughes acknowledges that the plans for crew support on the ISS are "embryonic" compared to the elaborate preparations needed for Mars explorers.

The risk of depression (and other dis-

## AD 1911

Roald Amundsen's team plants a Norwegian flag at the South Pole, and leaves a letter for the Briton Robert Falcon Scott, who arrives a month later. Brokenhearted, weighed down with scientific equipment, and lacking sled dogs, all five men in the British expedition perish on the return trip

## AD 1930

To explore the undersea world, Charles William Beebe and Otis Barton drop over 400 m in a spherical steel cabin tethered to a ship. They observe marine life never before seen by divers. Had the cable snapped, they'd have sunk to the ocean floor with no way to return

## AD 1957

David Simons, a US Air Force surgeon, ascends 31 110 m in a balloon and stays there for 32 hours to study the effects of high altitude on human health

## AD 1968

US astronauts Frank Borman, James Lovell and William Anders see the dark side of the moon on the Apollo 8 mission

orders like excessive fatigue, insomnia, headaches, and diarrhoea) also goes up when the body's circadian rhythms are upset. Circadian rhythms are cycles in hormone levels, body temperature, and other physiological changes, that are usually synchronised with the 24-hour Earth day. Mission planners will have to work out how to keep the astronaut's rhythms healthy as they move to a 24 hour and 37 minute "day" on Mars. "Light is the most important synchroniser for circadian rhythms," says circadian biologist Derk-Jan Dijk at Harvard Medical School in Boston. Mars is brutally cold, and the astronauts will be living in extremely well-insulated quarters which probably won't let in much natural light. Dijk thinks it likely that humans will be able to adjust to long periods of time on 24·6 hour days. But, he says, more studies are needed to work out exactly how to use artificial lights to keep Mars explorers in-synch with Mars.

***"We are breaking with our scheduled programming to bring you this news report. NASA has just announced that Rachel Blackwell, Explorer's electrical systems specialist, died yesterday of a kidney infection. Explorer 1 is due to splash down on 18 December, less than two weeks away. Doctors believe the infection, symptoms of which only appeared three days ago, progressed explosively because Blackwell's immune system had been weakened by prolonged stress and radiation exposure. Blackwell, like her crewmates, was also seriously dehydrated due to the failure of the water recycling system..."***

People get sick, and the crew of a Mars mission will be no exception. Sure, they'll be quarantined for weeks before they set off. And they'll be checked and rechecked for every disease known to humanity, their appendixes will likely be removed (just in case), and their genes and family histories probed for hints of a predisposition towards cancer, cardiovascular problems and mental instability. But they will be under constant physical and emotional stress, so their immune systems may not be in peak condition. That could make them susceptible to the normally benign organisms that inhabit every human body. Then, there's the possibility of accidents.

To cope, the crew will have medical supplies—essential drugs, diagnostic equipment, bandages, sutures and other basics—and very likely a doctor on board to do diagnosing, dispensing, bone-setting, and stitching up. But what if you need more? Say, an expert's opinion on whether an astronaut's chronic malaise is just fatigue or the forerunner to an impending medical catastrophe. Exactly how well equipped the ship's sick bay needs to be is open to debate.

Arnauld Nicogossian, NASA Associate Administrator for Life Sciences, outlines a medical system that includes continuous, noninvasive monitoring of each crew member's vital parameters like heart rate; miniaturised X-ray scanners and other diagnostic equipment; and arrays of biosensors to measure everything from contaminants in the air to microorganisms in the water. And, he says, shipboard data will have to be accessible to experts back on Earth so that they can provide the best possible medical advice.

Let's not get carried away, says Robert Zubrin, president of Pioneer Astronautics, an aerospace consultancy in Indian Hills, Colorado. "Explorers have always accepted risk," says Zubrin, who in the early 1990s outlined a Mars plan which now underpins NASA's ideas. For a Mars team, risk includes the fact that the nearest casualty department is on another planet.

According to Zubrin, even a full-time doctor is an unaffordable luxury. "You want a crack electrical engineer who knows some medicine rather than a doctor who has done some ham radio," he says. As for a doctor whose job would be to study the other crew members in the interests of learning more about space medicine, forget it. "He'd be out the airlock in three weeks—astronauts don't like to be studied."

Zubrin also claims that the biggest risk to the crew's lives will not come from a medical emergency—or radiation or microgravity or mayhem by a crazed crew mate—but from unforeseen mechanical failures. He has a point. No need to worry about cancer in your declining years if the rocket blows up. And any machine—be it for water recycling, air purification, communications, navigation, or the engines themselves—can break down, especially during a long mission that will strain the hardware in unimaginable ways.

No matter how well planned, the danger will be great. So why not send robots instead of humans? For reasons that go far beyond immediate practicalities, says Zubrin. "Mars presents the challenge of a new frontier, a place we can plant a new branch of human civilisation," he says. "For that, you need people."

***January 28, 2014, Arlington National Cemetery, Virginia. In a sombre ceremony, Explorer hero Rachel Blackwell was buried here today. Engineers at Marshall Space Flight Center in Alabama have identified the mutant fungus that destroyed the bacterial cultures used for water recycling, and which indirectly led to Blackwell's fatal infection. "As we mourn our loss today, we must remember," said President Karenna Gore, "the future belongs to the brave."*** □

*Robert Taylor* routinely has *Star Trek* dreams

## AD 1969

Neil Armstrong walks on the moon...and fluffs his famous line: "That's one small step for [a] man, one giant leap for mankind." Armstrong and Edwin Aldrin gather soil samples, set up a laser beam reflector that measures the distance to Earth, and conduct a solar wind experiment. Many Americans reportedly still believe that NASA faked the whole thing

## AD 1977

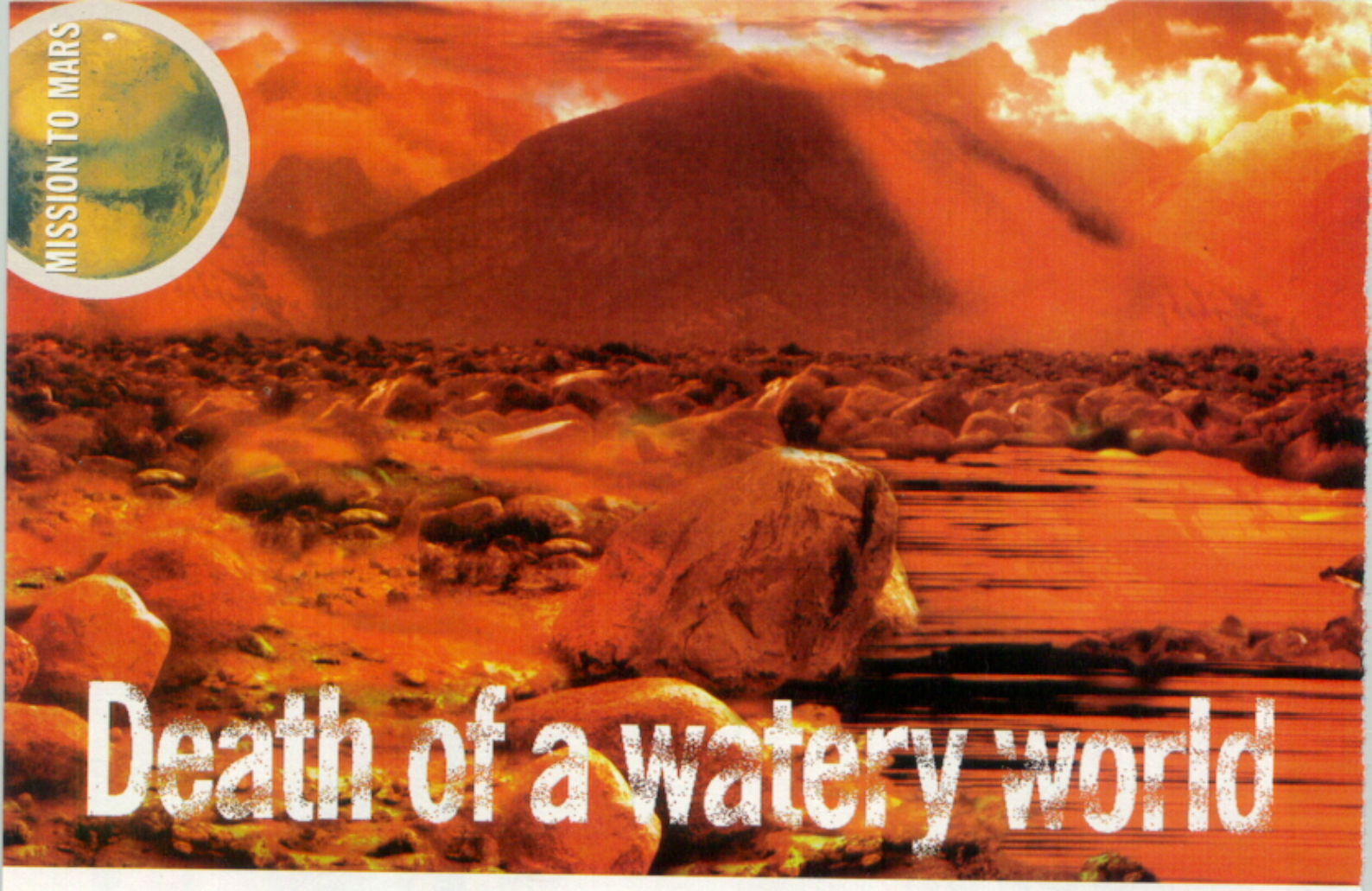
Robert Ballard, Jack Coreliss, and Jack Donnelly dive 2·5 km to the ocean floor in a submarine 8 m long called Alvin. Near the Galápagos Rift, where hot magma surges up from inside the Earth, they discover sulphur-eating bacteria and giant clams that live without light at temperatures over 380°C. The creatures spark new theories about the bare necessities of life

## AD 1981-97

The space shuttle fleet (Columbia, Challenger, Discovery, Atlantis, and Endeavour) makes around 90 flights to deploy satellites, fix space stations and telescopes and perform microgravity experiments. One shuttle doesn't make it. Seven lives are lost

## AD 2011

Mars?



# Death of a watery world

**With its next lander, NASA plans to discover what turned Mars from a warm, wet place to the cold, arid planet we see today, reports *Ralph Lorenz***

IN ITS YOUTH the Red Planet was very different from the frozen, barren desert we have seen on our TV screens courtesy of Pathfinder. The winding river valleys, shorelines and flood plains formed in those early times are clearly visible from space: proof that liquid water once flowed on Mars. It must have been warmer, too. And the planet's atmosphere must have been thicker to trap heat from the Sun and create enough pressure to prevent water from boiling away.

So what went wrong? Why did the Martian atmosphere vanish and what happened to the water that once flowed across its surface? Did the planet die from natural causes, or was it a case of suicide, or even murder?

Scientists hope to get some answers from the Mars Global Surveyor spacecraft, which entered orbit around Mars last week. Soon it will be photographing, measuring and studying the surface of Mars. But this is just the beginning of a much longer, more detailed mission. The Surveyor will enter a new phase of operation three years from now as a communications satellite for a Mars lander and two "penetrators" now under construction. Long after it has finished its main mission, the Surveyor will listen for radio signals from the ground, amplify them and retransmit them to Earth.

The mission designed to take advantage of the Surveyor's services—the Mars Volatiles and Climate Surveyor (MVACS)—will be launched in January 1999. It will land at the edge of the southern polar cap of Mars and study the climate, the soil and atmosphere, looking for the telltale evidence that will explain why Mars is now a dead planet.

There are three main theories and together they read like the plot of a detective novel. The first possibility is that Mars was murdered. The surface of Mars is scarred with craters from collisions with comets and asteroids. The blast from such impacts can blow away the atmosphere above the crater. And with enough large impacts, a substantial fraction of the atmosphere could be eroded. It would have been a slow, drawn-out death by suffocation.

## Sucked away

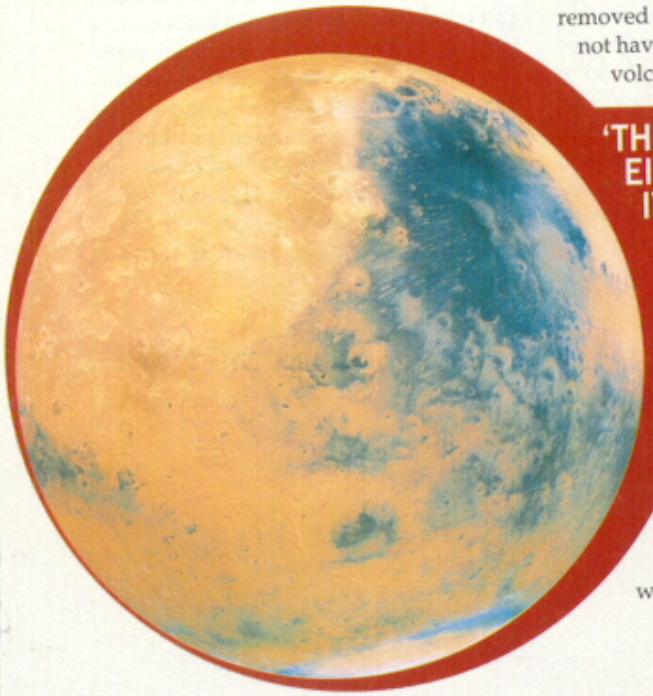
Another possibility is suicide. Mars would have needed a thick atmosphere of a greenhouse gas like carbon dioxide to keep it warm enough for liquid water to flow over its surface. And what little atmosphere it has today is mainly $CO_2$. Much of its $CO_2$ may have reacted with Martian silicate rocks to form chemicals called carbonates. If there was no other source of $CO_2$, the atmosphere would gradually have been sucked into the surface of the planet.

A similar process occurs on Earth, but here there is a carbon cycle to maintain the status quo. $CO_2$ is removed from the atmosphere by photosynthesis in plants. Carbonates such as limestone or chalk form from the shells of dead sea creatures

Illustrations: Charlie Ward/ US Geological Survey SPL

that fall to the ocean floor, removing their carbon from the cycle. But $CO_2$ is also pumped back into the atmosphere by volcanic activity. The net effect is that $CO_2$ levels remain roughly constant.

The evidence for the suicide scenario comes from Martian meteorites that have landed on Earth. Small amounts of carbonates have been found in these rocks, and some scientists believe that this supports the claim that life once existed on Mars. But carbonates can form by purely physical processes too—as in the reaction between $CO_2$ and silicates—if the conditions are right. Either way, once $CO_2$ was removed from the atmosphere, it would not have been replaced since Mars is not volcanically active.

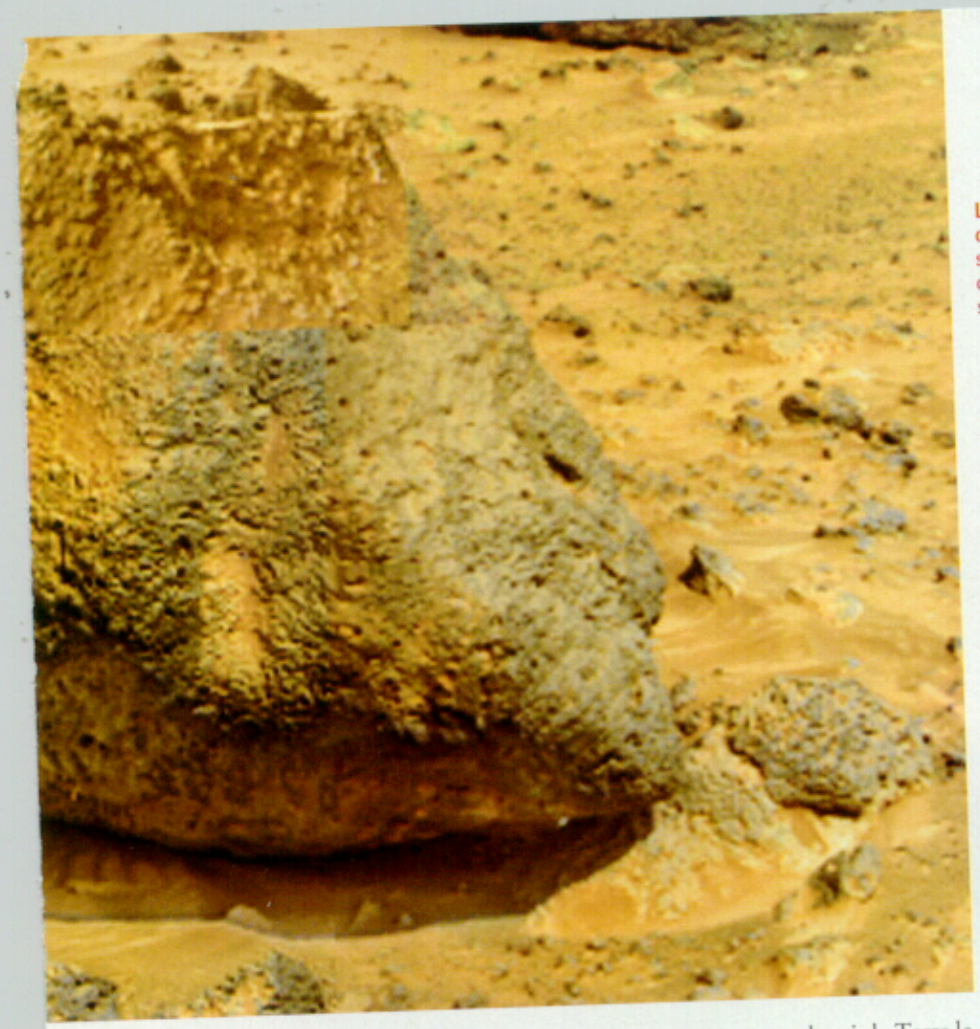


**'THERE ARE THREE OPTIONS: EITHER MARS WAS MURDERED, IT COMMITTED SUICIDE, OR IT DIED OF NATURAL CAUSES'**

The final possibility is that the Red Planet died of natural causes. Mars has an orbit that is more eccentric than the Earth's, so the amount of sunlight it receives during the year varies hugely. The axis of the planet may also have tilted sharply in the past so that winters were very severe. Combinations of changes in tilt and orbit, the so-called Milankovitch cycles, are believed to be responsible for the onset of ice ages on Earth. Mars may be in the middle of a similar ice age in which much of its $CO_2$ atmosphere has condensed to form permafrost at the poles or beneath the entire surface. This would be hidden from orbiting spacecraft.

Martian ice ages may be self-perpetuating. A thinner atmosphere would be less effective at transporting heat from the equator to the poles. Because of this, the poles would stay cold, keeping the $CO_2$ locked up even when a change in the planet's eccentricity and tilt made the winters less severe. This may have locked Mars into a permanent ice age.

The only way to decide which of these scenarios is most likely is to land a craft at the poles, or at least nearby, to look for evidence. This is just what the next mission will do. Images from Mariner 9, which orbited Mars in 1971, and the Viking orbiters from the mid-1970s show strange layered terrain at the edge of



Le choix du terrain pour procéder aux différentes missions de retour d'échantillons sera déterminant. Les chercheurs américains ont présélectionné plus d'une centaine de sites intéressants.

cune de ces missions, de remplir son conteneur de mini-prélèvements de sol, et cela jusqu'à épuisement de ses réserves d'énergie. En 2005, un atterrisseur aurait dû se poser à proximité de l'un des deux robots avant de décoller vers la Terre avec le précieux chargement. Exigeant une précision diabolique, un tel rendez-vous était quasi impossible. La nouvelle mouture apparaît plus réalisable. Cette fois, c'est la sonde retour qui aura la responsabilité de localiser, puis de rattraper, les deux capsules d'échantillons : celle de la mission 2003, en attente depuis deux ans, et celle de 2005.

Si le pari est moins risqué que dans le scénario précédent, cette partie de chasse autour de Mars s'annonce tout de même *"extrêmement sportive"*, prévient Francis Rocard. Le gibier sera constitué d'étuis sphériques de 20 cm de diamètre, placés en orbite avec une précision aléatoire. *"Dans sa version d'origine, celle de la Navy, l'engin qui faisait office de MAV pesait 700 kg et était doté de moteurs cryogéniques,* explique Francis Rocard. *Celui dont nous disposerons est sept fois moins lourd et ses trois moteurs à poudre réduiront très sensiblement la précision de mise en orbite."* Première difficulté, donc : localiser la capsule contenant les échantillons de 2003. La caméra de Mars Express aura, en principe, eu le temps de la repérer et de la suivre. Avec un peu de chance, les antennes du Deep Space Network de la Nasa auront peut-être réussi à capter depuis la Terre le "bip bip" lancé par son émetteur radio. Si tout va bien, les paramètres de son orbite seront donc connus et la chasse pourra commencer.

## Les États-Unis pensent déjà à des missions pour 2007-2009, et même au-delà

L'orbiteur traquera son gibier par radio d'abord, puis par navigation optique. En fin d'approche, un système de guidage automatique par laser prendra la relève, jusqu'à ce que le conteneur soit "gobé" par la capsule de rentrée atmosphérique terrestre, fixée sur la sonde. *"Avec de la chance, il nous restera du temps pour récupérer le second conteneur, celui de la mission 2005. Sinon, nous l'abandonnerons,* commente Francis Rocard. *Tout dépendra de la date de lancement car, si la fenêtre de tir en 2005 dure trois semaines, la date de rentrée, elle, est immuable. Si on ne la respecte pas, on manque d'ergols pour le retour."* Pour l'ingénieur du Cnes, la récupération d'un seul conteneur serait déjà un succès. *"C'est une mission ambitieuse et difficile. Un peu l'équivalent du concept Apollo, mais en automatique, mille fois plus loin de la Terre et avec des budgets sans commune mesure."*

Les Américains semblent en tout cas confiants. Ils ont déjà porté sur leur proposition de planning des missions identiques à celles de 2003-2005 pour 2007-2009 et pour 2011-2013. Il est vrai qu'ils ont aussi prévu une solution de repli en cas de défection française. Si Ariane 5 n'est pas disponible, il n'y aura ni atterrisseur ni rover en 2005 et la Delta 3 ne lancera cette année-là que l'orbiteur destiné à récupérer les échantillons de la mission 2003. Mais *a priori,* c'est la version haute, avec le lanceur et la sonde promis par la France, qui prévaut. La Nasa s'est même montrée intéressée par le concept de "micro-missions" proposé par le Cnes. Des sondes de 200 kg (70 kg hors ergols et moteur) qu'Ariane 5 emporterait en passagers supplémentaires lors de tirs commerciaux. Les Américains se disent prêts à réaliser eux-mêmes ces petits engins, dont ils évaluent le coût à 50 millions de dollars pour un modèle unique (35 s'ils sont fabriqués en série). Ils pourraient emporter des expériences (mini-rovers, ballons, etc.) susceptibles de tester les futurs sites d'atterrissage, ou servir de relais de télécommunications en orbite martienne. Ce qui permettrait à la Nasa de réaliser la couverture médiatique sur Internet dont elle rêve pour la mission 2005. Huit de ces micro-missions sont déjà inscrites au planning : deux en 2003, quatre en 2005 et deux en 2007. Reste à les financer.

En attendant, les deux partenaires peaufinent leurs projets et tentent d'accorder leurs rêves à leurs moyens. Côté français, seul l'orbiteur cause encore quelques soucis aux ingénieurs du Cnes. Il s'agit d'une première technologique pour la France et la fourchette de 400 à 800 millions de francs prévue à ce jour pour sa réalisation sera peut-être difficile à respecter. En revanche, le budget de 400 millions de francs affecté aux quatre mini-stations Netlander ne devrait pas être dépassé, estiment les responsables du projet. D'ici là, Français et Américains vont échanger leurs signatures au bas de lettres d'accord et, dans les deux ou trois mois qui viennent, d'un document décrivant dans le détail les tâches des uns et des autres. À première vue, rien ne semble devoir enrayer le cours de cette belle aventure qui marquera l'entrée en force de la France sur la scène martienne. ■

*(1) Avec une participation du Centre d'étude des faibles rayonnements, à Toulouse, qui a mis la main à ce spectromètre gamma.*

# Le temps des robots

Pour Daniel McCleese, responsable scientifique de l'exploration martienne au JPL, cela ne fait pas l'ombre d'un doute. La Nasa continuera en 2009 et au-delà *"d'aller chercher des échantillons sur Mars"*. *"Et quelle que soit la tournure que prendront les choses,* poursuit-il, *nous aurons besoin de robots mobiles. Même si nous envisageons déjà de lâcher, durant la descente des atterrisseurs, des petits avions capables d'explorer un vaste périmètre autour du site d'atterrissage, les robots auront un rôle clé à jouer. D'où la nécessité de renforcer leurs performances dans tous les domaines."*

Le maître mot, c'est l'autonomie. Conçus sur la base de l'expérience acquise avec Mars Pathfinder, les futurs véhicules utiliseront dans un premier temps, pour se déplacer, des repères identifiés sur des images faites par l'atterrisseur. Plus tard, ils seront en mesure de faire la même chose grâce à leur propre système d'imagerie stéréo. Les scientifiques sélectionneront alors des repères et des cibles, et c'est l'ordinateur du robot qui déterminera le meilleur chemin pour atteindre l'objectif.

Les performances de ces futurs robots se jugeront ainsi à leur capacité à transporter, depuis un atterrisseur, des instruments sophistiqués et à collecter des données sur les roches et le sol dans des zones parfaitement vierges.

Autant de défis technologiques que la Nasa a choisi d'affronter par étapes. En 2001, le rover Marie Curie ne sera rien d'autre que la doublure de celui de Mars Pathfinder avec, pour seul équipement, un instrument d'analyse des roches, enrichi d'une foreuse capable de prélever de minuscules carottes.

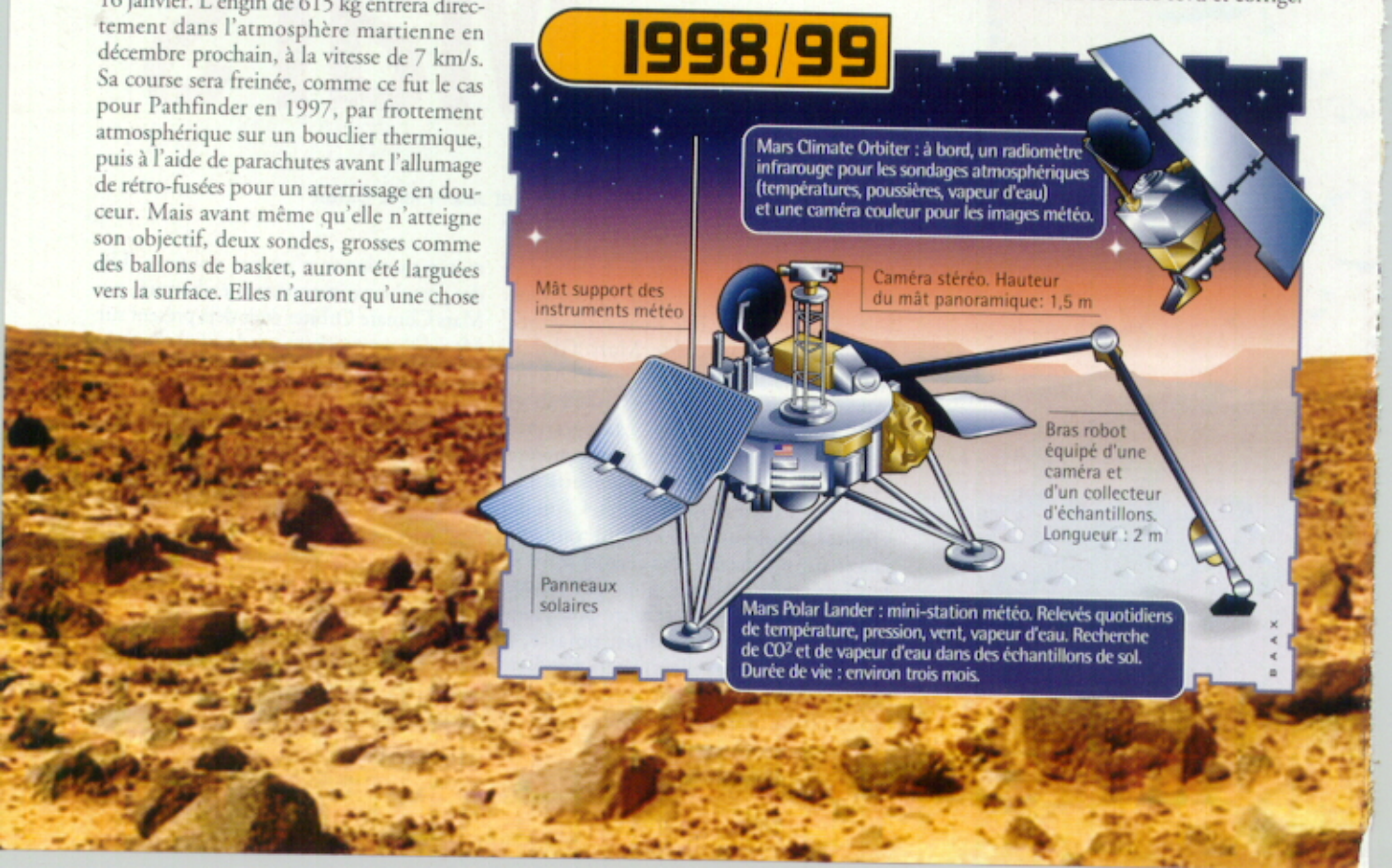
Les choses plus sérieuses commenceront en 2003. Le rover sera plus lourd (une soixantaine de kilos) et ressemblera déjà, selon Daniel McCleese, à *"un laboratoire mobile"*, avec caméra, bras articulé, mini-foreuse et instruments d'analyse. *"Il procédera à une centaine de carottages"* jusqu'à 5 cm de profondeur, afin *"de recueillir des échantillons protégés des ultraviolets ou des agressions chimiques de surface"*. Autre ambition de la Nasa, tenter dès 2003 des sondages plus

les traces qu'ont pu laisser, à la surface de la planète rouge, les grands épisodes de son passé climatique.

## Le rover fera des allers et retours en pétales pour sélectionner un kilo de roches

Mars Polar Lander suivra entre le 3 et le 16 janvier. L'engin de 615 kg entrera directement dans l'atmosphère martienne en décembre prochain, à la vitesse de 7 km/s. Sa course sera freinée, comme ce fut le cas pour Pathfinder en 1997, par frottement atmosphérique sur un bouclier thermique, puis à l'aide de parachutes avant l'allumage de rétro-fusées pour un atterrissage en douceur. Mais avant même qu'elle n'atteigne son objectif, deux sondes, grosses comme des ballons de basket, auront été larguées vers la surface. Elles n'auront qu'une chose à faire : s'enfoncer de 2 m dans le sol et dire si celui-ci contient de la glace ou pas. Quant à Mars Polar Lander, elle réalisera une première en s'installant à la limite de la calotte glaciaire, entre 75 et 80° de latitude sud. Jamais une sonde ne s'est encore posée aussi près d'un pôle martien. Une belle promesse d'images en perspective, dévoilant des paysages pratiquement inconnus à ce jour. Pendant au moins trois mois, entre la fin du printemps et le début de l'été austral, cette petite station météo, équipée d'une caméra stéréoscopique, d'un bras télémanipulateur et d'un Lidar fourni par l'agence spatiale russe, guettera le moindre indice de changement climatique à la surface et étudiera les fluctuations saisonnières de l'eau, du dioxyde de carbone et de la poussière. Voilà pour l'édition 1998-1999.

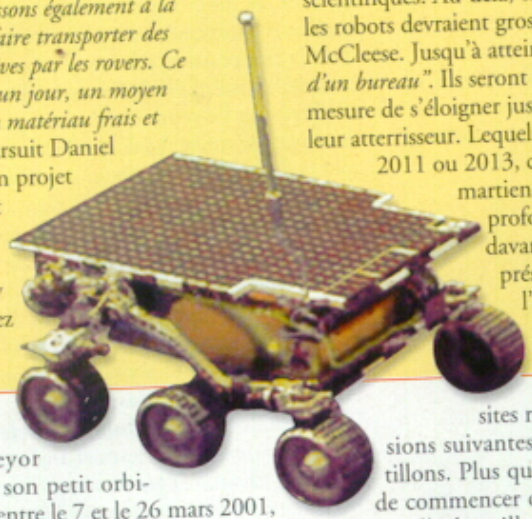
Un nouvel épisode débutera deux ans plus tard avec, comme prévu de longue date, deux sondes, une en orbite et une au sol, mais selon un scénario revu et corrigé.



profonds à partir de l'atterrisseur. *"Peut-être jusqu'à 1 m."* Auquel cas, le mobile serait appelé à jouer un rôle. Il pourrait être chargé, par exemple, d'aller chercher les prélèvements sur la foreuse de l'atterrisseur et de les déposer dans la capsule de retour.

*"Nous réfléchissons également à la possibilité de faire transporter des charges explosives par les rovers. Ce pourrait être, un jour, un moyen d'accéder à du matériau frais et profond"*, poursuit Daniel McCleese. Un projet pour l'instant hors course. Au JPL, on estime qu'il y aura déjà assez à faire pour mener à bien les missions de 2003 et de 2005, sans qu'il soit nécessaire de se compliquer la vie avec des explosifs et les risques de contamination du sol qu'ils impliquent. En 2005, le rover sera le cousin germain de celui de 2003. Seuls différeront légèrement ses équipements scientifiques. Au-delà, en 2009 ou 2011, les robots devraient grossir, prédit Daniel McCleese. Jusqu'à atteindre *"la taille d'un bureau"*. Ils seront également en mesure de s'éloigner jusqu'à 10 km de leur atterrisseur. Lequel pourrait, en 2011 ou 2013, creuser le sol martien jusqu'à 5 m de profondeur. Faire davantage suppose la présence de l'homme.

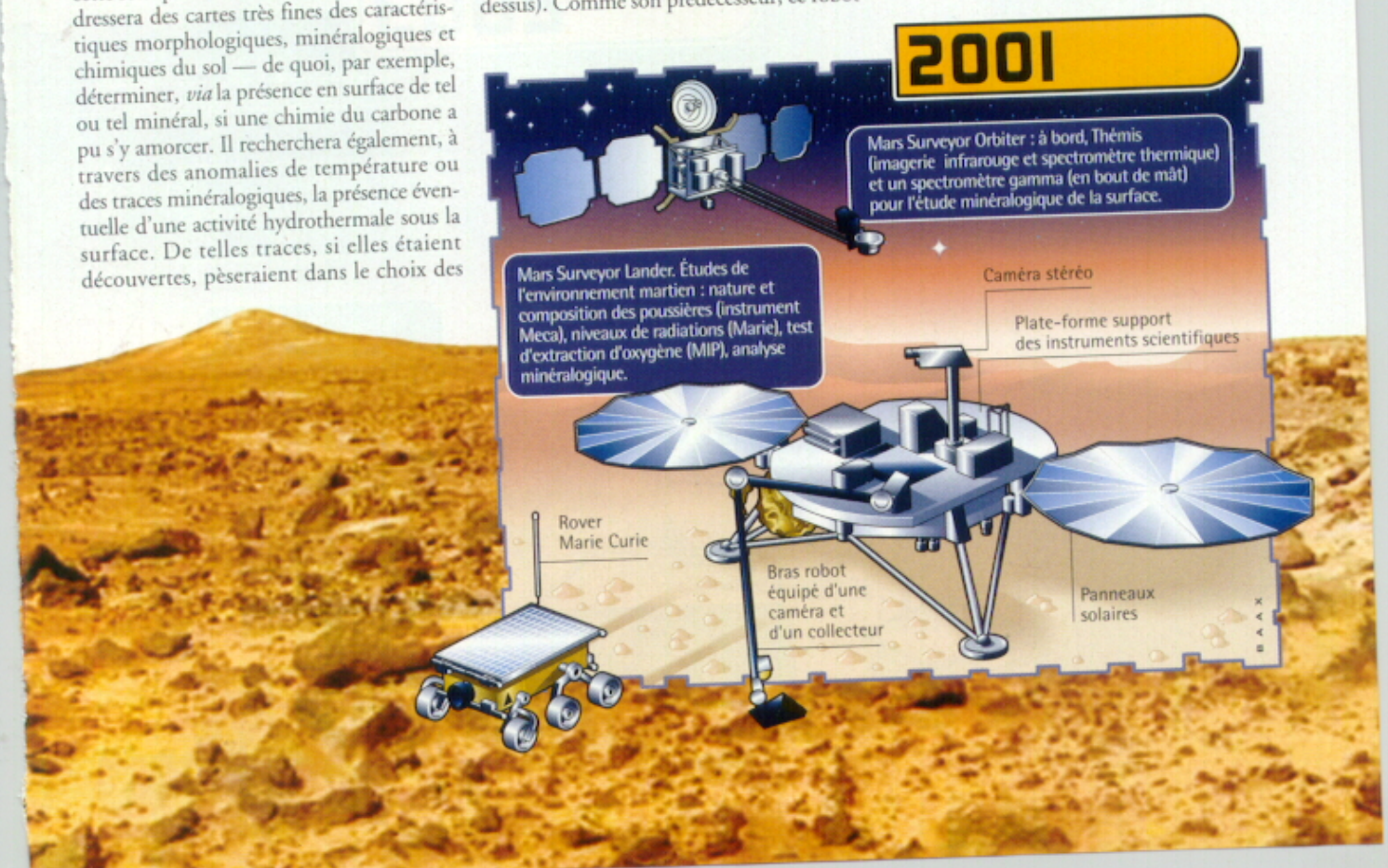
William Harwood



Photos Nasa

La mission Mars Surveyor 2001 garde son petit orbiteur. Lancé entre le 7 et le 26 mars 2001, celui-ci se mettra en orbite polaire en décembre de la même année, à 400 km d'altitude, et ce pour trois ans au cours desquels devrait être franchie une nouvelle étape dans l'inventaire que la Nasa entend dresser de la planète rouge. C'est la surface cette fois qui sera à l'honneur. Cet orbiteur dressera des cartes très fines des caractéristiques morphologiques, minéralogiques et chimiques du sol — de quoi, par exemple, déterminer, *via* la présence en surface de tel ou tel minéral, si une chimie du carbone a pu s'y amorcer. Il recherchera également, à travers des anomalies de température ou des traces minéralogiques, la présence éventuelle d'une activité hydrothermale sous la surface. De telles traces, si elles étaient découvertes, pèseraient dans le choix des sites retenus pour les missions suivantes de retour d'échantillons. Plus question, en revanche, de commencer dès cette mission les collectes d'échantillons, comme la Nasa l'avait envisagé jusqu'à présent. Plus question, non plus, de rover sophistiqué. Mars Surveyor 2001 se contentera du modèle de rechange du Sojourner emporté par Mars Pathfinder en 1996, et baptisé pour la circonstance Marie Curie (voir encadré ci-dessus). Comme son prédécesseur, ce robot de poche descendra fixé sur une petite station fixe, dont il ne s'éloignera pas de plus de quelques mètres. Avec sa caméra stéréo et ses dispositifs d'étude *in situ* des roches et de la poussière du sol, cette station de mesure sera en revanche plus sophistiquée que celle de Mars Pathfinder ou de Mars Polar Lander. Lancée entre le 5 et le 24 avril 2001, elle devrait être à poste fin janvier 2002.

Les changements sont encore plus impressionnants pour 2003. À la différence des deux épisodes précédents, l'orbiteur américain disparaît — son rôle devant éventuellement être tenu par Mars Express, la sonde que l'Agence spatiale européenne projette d'envoyer vers Mars en 2003. En revanche, c'est là que commenceront vraiment les collectes d'échantillons. Sous la coiffe d'une fusée Delta 3, la Nasa aura logé un atterrisseur emportant lui-même un rover et une petite fusée, le MAV. Ce Mars Ascent Vehicle, version miniaturisée d'un véhicule de transfert mis au point par l'US Navy dans les années 60, est destiné à placer en orbite martienne des échantillons récoltés à la surface. Le rover sera équipé de l'ensemble d'instruments baptisé Athéna que l'université Cornell avait conçu au départ pour la mission de 2001. Dans le programme initial, il devait pendant un an recueillir des échantillons sur *"au moins 10 km"*, avant de s'arrêter pour attendre la relève, en 2005 ou 2006. Trop risqué. Il se



contentera d'effectuer des allers et retours "en pétales" autour de l'atterrisseur, où il viendra déposer, par petites quantités, le kilo de roches sélectionnées lors de ses courts trajets. Il parcourra ainsi plusieurs kilomètres au compteur, mais son rayon d'action sera limité à quelques dizaines de mètres autour de sa base.

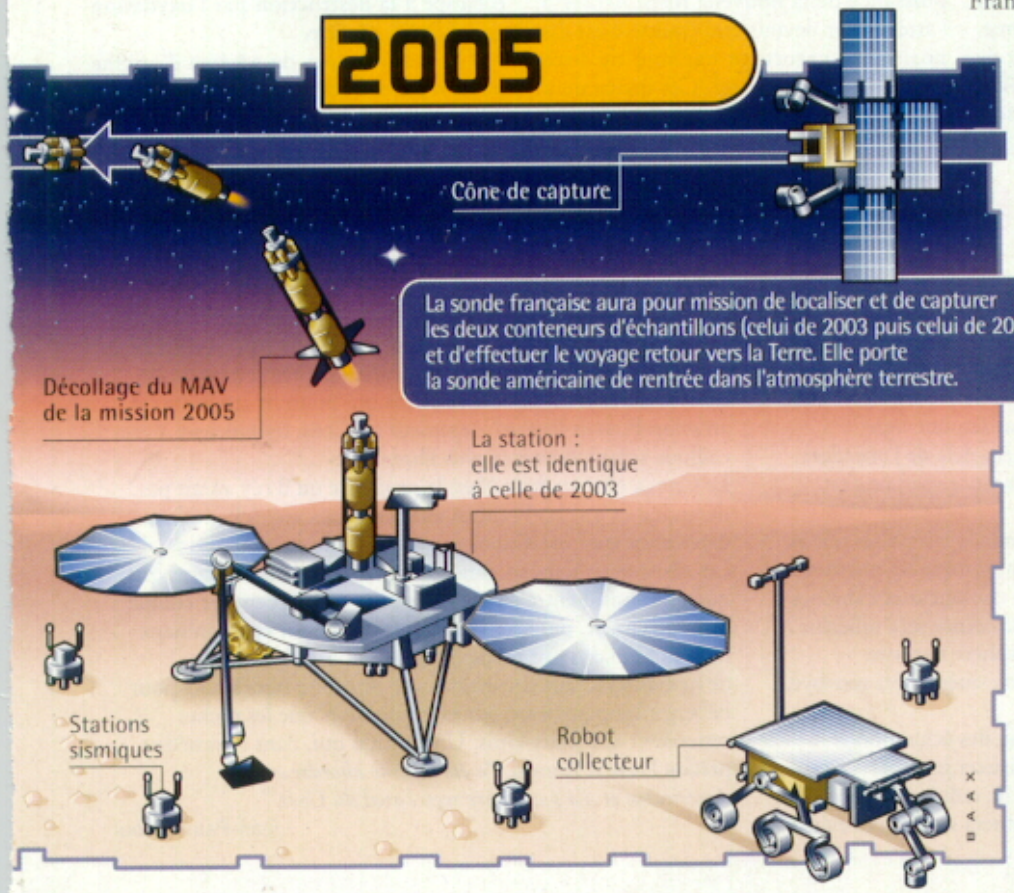
Plusieurs raisons expliquent ce chamboulement opéré durant l'été dernier par une équipe du Jet Propulsion Laboratory (JPL), le centre de la Nasa responsable de l'exploration planétaire. D'abord, l'agence américaine s'est aperçue qu'elle était en train de mordre la ligne rouge qu'elle s'était fixée en matière budgétaire (200 millions de dollars par an, en moyenne, sur dix ans). Ensuite, le robot qu'elle envisageait pour 2001 était bien plus difficile à réaliser que prévu. Enfin, et surtout, elle avait l'opportunité de s'adapter à une proposition française qui lui laissait entrevoir de substantielles économies tout en améliorant le retour scientifique des missions. *"Tout a commencé il y a environ un an"*, raconte Christophe Sotin, directeur du Laboratoire de géodynamique et de planétologie à l'université de Nantes et président du "groupe Système solaire" au Cnes. Lors de sa visite, en octobre 1997, à Paris, Daniel Goldin, le patron de la Nasa, avait en effet demandé à nouveau au gouvernement français de fournir une Ariane 5 pour le programme martien de la Nasa. *"Une requête formulée deux ou trois ans plus tôt, sans grande réaction de Paris."* Elle trouve un écho plus favorable à la fin 1997. D'une part, le Cnes se cherche un grand programme pour l'après-2000 et dispose d'un budget pour cela. D'autre part, Claude Allègre, le ministre chargé de l'Espace, est très intéressé par l'exploration planétaire et entend affirmer la particularité française au sein de l'Europe spatiale.

## Des chiffres qui donnent la mesure de l'effort décidé par la France

Les choses, dès lors, vont aller très vite. En février, le JPL vient à Paris présenter son projet "Retour d'échantillons", qui sera étudié par les chercheurs français réunis à Arcachon le mois suivant afin de préparer le programme scientifique spatial des années à venir. En juillet et en août, un groupe de travail se réunit à Pasadena (Californie). En font partie côté Cnes Jacques Blamont, conseiller auprès de la direction, Richard Bonneville, directeur des programmes, Francis Rocard, responsable de l'exploration planétaire, Michel Courtois, directeur du centre toulousain, plus particulièrement chargé des évaluations techniques, et des scientifiques français.

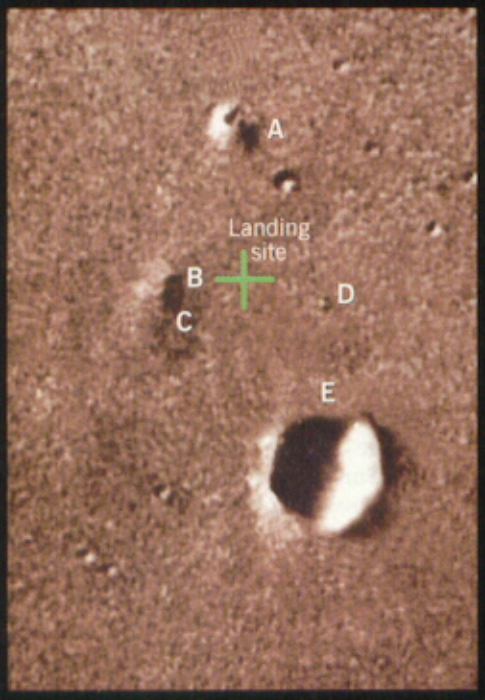
La remise à plat est assez radicale. *"Le programme initial était axé presque exclusivement sur l'exobiologie*, explique C. Sotin. *De notre côté, nous estimions qu'il était impossible de dissocier l'apparition éventuelle de la vie sur Mars de l'évolution globale de la planète, un domaine d'autant plus intéressant qu'il est de nature à nous faire mieux comprendre comment la Terre fonctionne."* Ce choix de l'exobiologie par la Nasa était guidé essentiellement par des considérations médiatiques, le but étant d'accrocher le public américain pour amener le Congrès à accorder les financements nécessaires. Une contrainte que l'apport financier de la France devait en partie lever. Le Cnes a en effet décidé d'affecter près de deux milliards et demi de francs à ce programme. La Nasa, de son côté, dispose de deux milliards de dollars sur dix ans pour l'exploration martienne. Des chiffres difficilement comparables si l'on ne tient pas compte des salaires et des différences de coût d'un côté et de l'autre de l'Atlantique, mais qui donnent la mesure de l'effort décidé par la France : *"Notre participation*, souligne Francis Rocard, *dépasse largement 20 % de l'ensemble"*. Selon des calculs officieux effectués par les experts américains, l'économie pour l'agence spatiale américaine atteindrait environ 710 millions de dollars.

La France fait donc une entrée en force dans l'exploration martienne. Si tout se passe comme prévu, elle occupera même une position clé dans la mission Mars Surveyor 2005, point d'orgue du nouveau plan de la Nasa, avec la première tentative jamais faite de rapporter un peu de Mars sur Terre. Le Cnes fournira le lanceur, une Ariane 5. Sensiblement plus puissante que la version qui vient de réussir son entrée en service, celle-ci emportera 5 tonnes vers la planète rouge. De quoi expédier en un seul tir, et pour 800 millions de francs, la totalité du matériel — sonde, station au sol et autre robot nécessaire à l'expédition. Premier "client" important de cette Ariane 5 : une sonde de 2,7 tonnes, autre grosse participation française. Destinée à se satelliser autour de Mars, elle assurera le voyage du retour et portera, accrochée à son flanc, la capsule de fabrica-

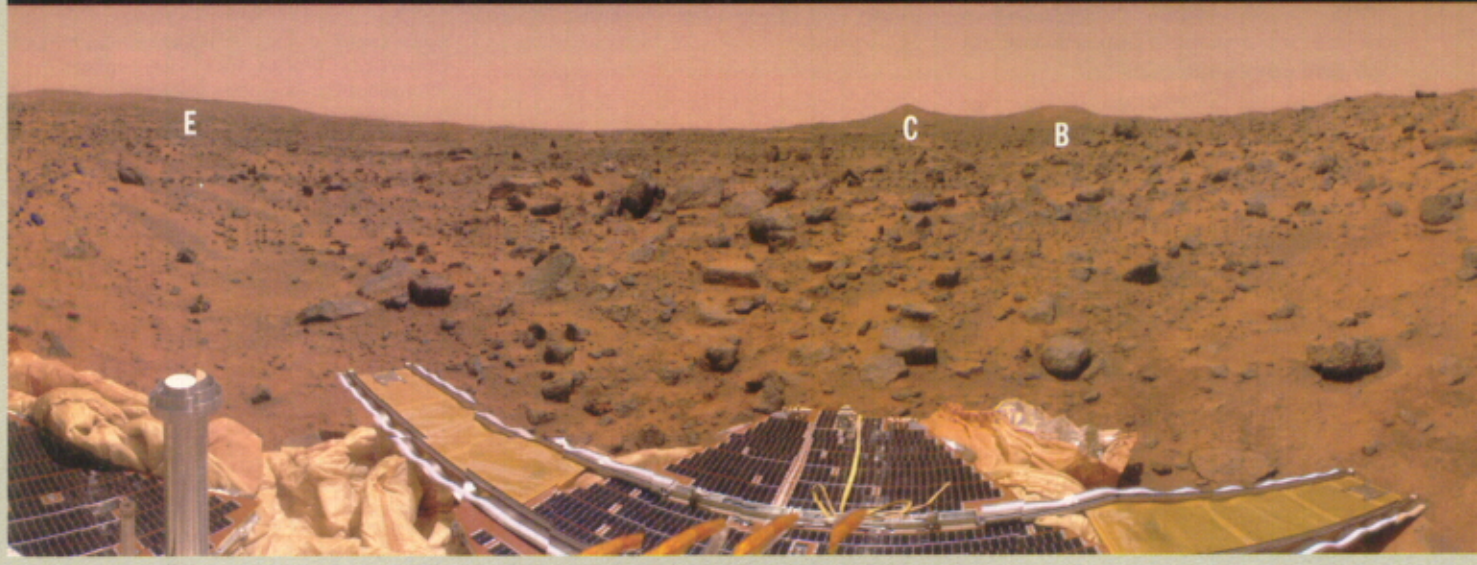


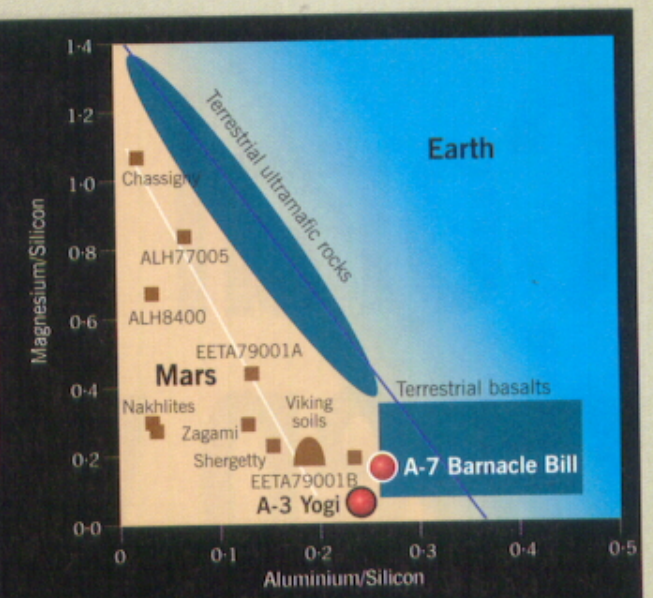
# Postcards from another planet

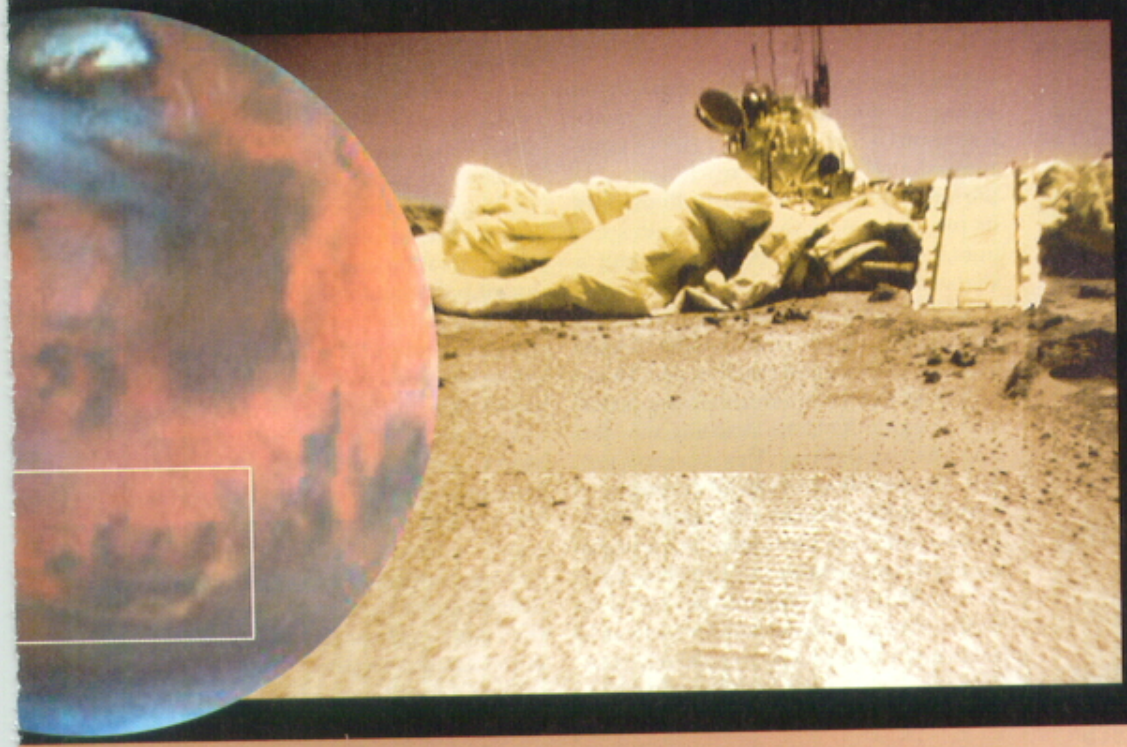
## For the price of a Hollywood movie, Pathfinder has given us stunning pictures of an alien world



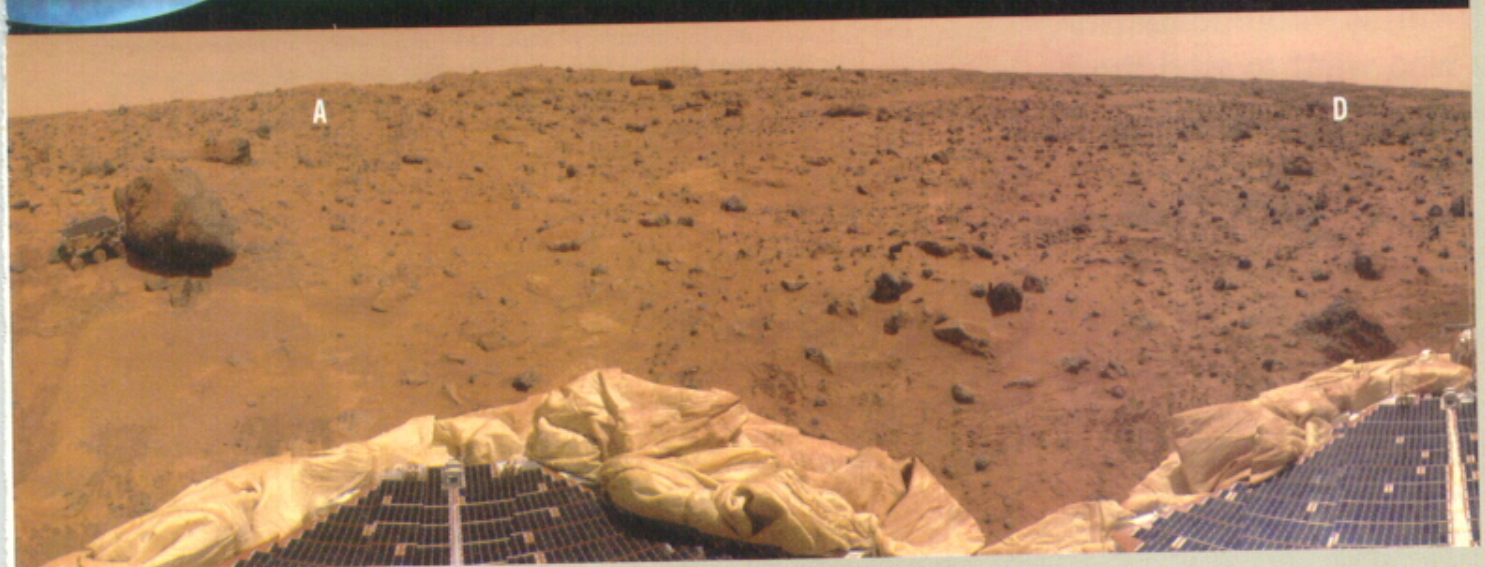
Zooming in: one week before touchdown, the Hubble Space Telescope spots a sandstorm (the yellow coloration) developing a few hundred kilometres south of the landing site (green cross). On 4 July, Pathfinder touches down sending back spectacular images of the surface. Nearby features (A,B,C,D,E) can even be matched with an overhead view of the landing site taken by Viking in the 1970s. Fears that the sandstorm would spread prove unfounded although the weather could yet turn nasty





**Data stream: sunset on Mars (above left) turns out to be just as spectacular as on Earth. The colour of the sky can help scientists work out the size of particles in the atmosphere. The rover, Sojourner, has photographed the lander (left) and analysed rocks nearby (above). The results are surprising. Two nearby rocks, Yogi and Barnacle Bill, are much more similar to Earth rocks than either the soils analysed by Viking or the Martian meteorites found on Earth (designated ALH..., EETA... or by the names of the places where they were found)**




NASA/JPL

abundance shows how fast the atmosphere has escaped in the past.

The mission will also test a pair of torpedo-shaped "penetrators", which will be dropped before the main lander enters the atmosphere. Each weighs about 2·5 kilograms and is protected from burning up by ceramic heat shields. They will hit the ground 100 kilometres north of the MVACS lander site at a speed of about 190 metres per second—enough to bury the penetrator to a depth of up to 2 metres.

Each will carry an accelerometer to record the atmospheric drag and the impact with the surface. This will tell researchers whether the surface is layered. A small drill will scrape a sample of soil into a thimble-sized metal cup. This will then be heated and a tiny spectrometer the size of a postage stamp will look for any water that is produced.

None of this information can be transmitted back to Earth from beneath the surface, so the tail of each penetrator is designed to detach on impact and reel out a cable connected to the main body. The tail carries a pressure sensor and small antenna which will radio the data to the Mars Global Surveyor spacecraft orbiting above. With pressure sensors on each penetrator and the lander, it may be possible to monitor the passage of storm systems over the surface.

## Penetrating insights

The penetrators should continue working for a couple of days, and maybe longer, if their batteries survive the impact. It's a big "if"—the penetrators will strike the surface with a force equivalent to 80 000 times their weight here on Earth. No penetrator has successfully reached another planet or moon. The Japanese space agency ISAS plans to send penetrators to the Moon next year and the Russian space agency's Mars 96 mission carried two, but they were lost along with the rest of the mission when its booster misfired. While the latest attempt may provide valuable data, its main objective is to show that penetrator technology works.

Meanwhile, the MVACS lander should continue collecting data for much longer, up to seven months during the Martian summer in 1999. During that time it should provide vital clues to the planet's cause of death. But as winter sets in and the Sun sinks low on the horizon, MVAC's solar panels will stop producing power to operate the lander. As $CO_2$ frost begins to form around it, MVACS will fall silent.

But this may not be the end. Scientists hope that the following spring, almost 400 days later, MVACS will come back to life. By that time, the next salvo of Mars missions will be on its way. □

***Ralph Lorenz*** is a research associate at the University of Arizona. He models climates throughout this and other solar systems and is working on the TEGA experiment

***Further reading:*** the MVACs home page is at **http://mvacs.ess.ucla.edu/mvacs/index.html**

**20 July 1976**

Viking 1 touches down on the surface armed with a set of experiments to search for signs of life. The mission is a huge success but it is accidentally shut down on 13 November 1982 and communications are never re-established

**2 September 1988**

The Soviet spacecraft Phobos 1 is lost en route due to a command error. It had been due to place a lander on the Martian moon of the same name

**21 August 1995**

NASA's $1 billion Mars Observer vanishes as it approaches Mars

**16 November 1996**

The Russian Mars 96 spacecraft crashes back to Earth soon after launch

**4 July 1997**

Mars Pathfinder lands on Mars and deploys the Sojourner rover—the first vehicle to be deployed on the surface of another planet. It is the first successful mission to Mars for 20 years

**12 September 1997**

The Mars Global Surveyor arrives at Mars

# USA, France, Europe

Alors que Mars Global Surveyor, en poste depuis plus d'un an, se prépare à un survol rapproché, deux nouvelles sondes sont à leur tour en partance pour la planète rouge. Ce n'est encore qu'une avant-garde mais elle annonce la grande offensive de la Nasa, qui culminera en 2005 avec la première tentative pour rapporter sur Terre une poignée de cailloux et de poussières. Une aventure où la France vient de faire une entrée en force.

# La ruée vers Mars

Jean-Paul Dufour et Jean-Pierre Defait

LA Nasa avait promis de bombarder Mars à raison de deux sondes tous les deux ans. Elle tient ses engagements. Alors que Mars Global Surveyor (partie le 6 novembre 1996, un mois avant Pathfinder) entamera dans quelques semaines une cartographie détaillée de la planète rouge, la première vague de cette grande offensive martienne est en route. En tête, Mars Climate Orbiter. La sonde de 633 kg devait être lancée par une fusée Delta 2 entre le 10 et le 17 décembre dernier, pour une arrivée autour de Mars en septembre prochain. Placée sur une orbite quasi polaire, à 400 km d'altitude, elle dressera pendant deux ans la carte du climat et de ses variations saisonnières. Cet intérêt pour la météo martienne n'est pas nouveau. Un des principaux instruments embarqués sur Mars Climate Orbiter était déjà présent sur Mars Observer, cette sonde perdue par la Nasa alors qu'elle abordait la planète rouge, en août 1993. Objectif : sonder l'atmosphère et mesurer ainsi aussi bien les variations de température que les concentrations de poussières, de gaz carbonique ou de vapeur d'eau. Mais figure également au menu de ces deux années d'observation l'étude des nuages, du régime des vents et de leur rôle dans l'érosion de la surface, avec une attention toute particulière pour les célèbres tempêtes de poussières qui affectent régulièrement la planète rouge. Enfin, les astronomes espèrent retrouver, grâce aux images de Mars Climate Orbiter,

Photos Nasa

# Quel site, et pour quoi faire ?

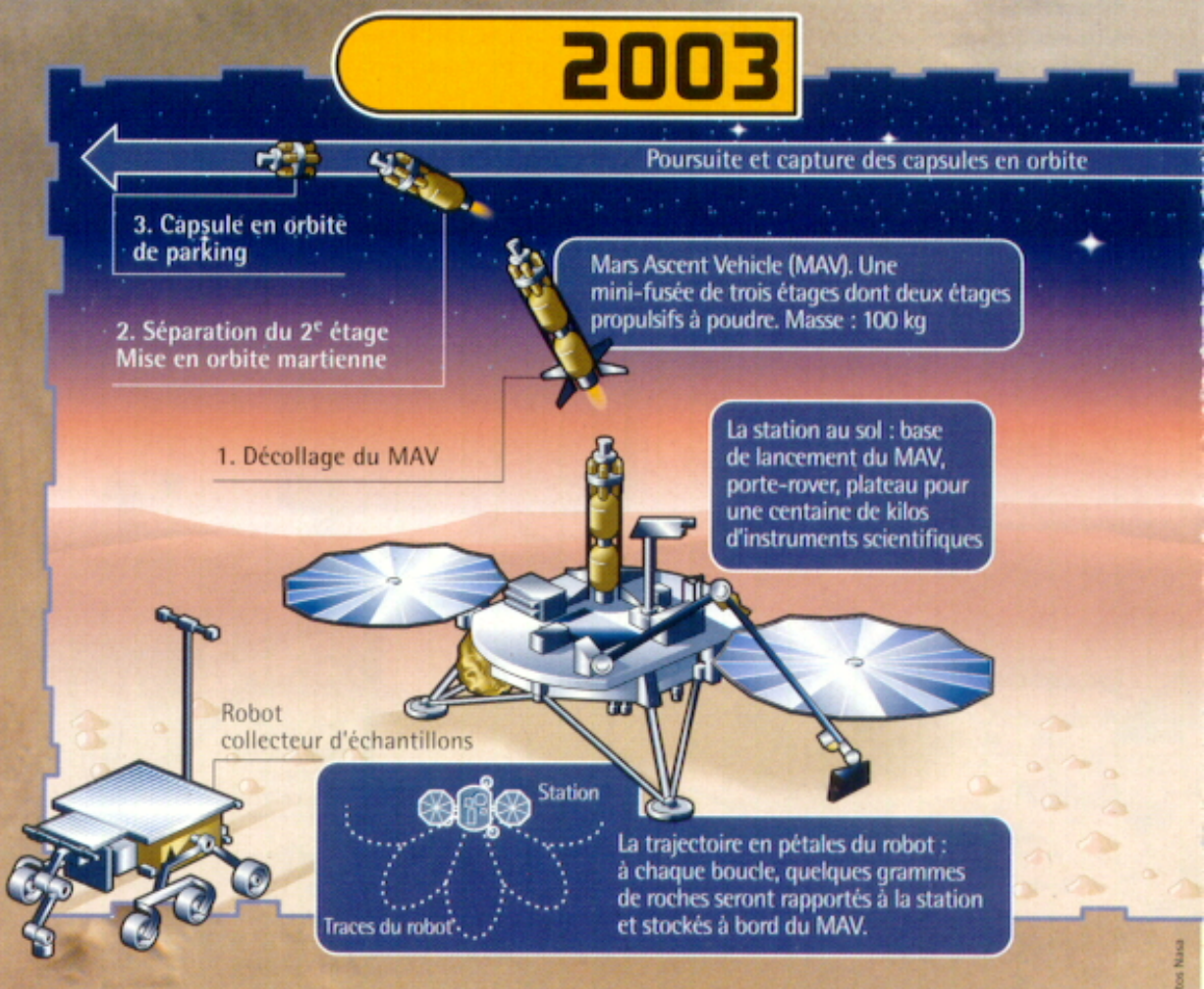
Exobiologistes, géochimistes et spécialistes de l'atmosphère ne rêvent pas des mêmes cailloux martiens. Pour les premiers, l'échantillon parfait est un sédiment, un calcaire par exemple, qu'il faudrait aller chercher à 1 m de profondeur dans des dépôts lacustres ou dans un ancien lit de rivière. *"Les éventuels micro-organismes présents dans l'eau ont pu être piégés dans ces roches"*, explique André Brack, du Centre de biophysique moléculaire d'Orléans. Un échantillon ayant été en contact avec une source hydrothermale qui, sur Mars, aurait pu fonctionner bien après la disparition des rivières de surface leur conviendrait également. Bref, les exobiologistes veulent des roches du sous-sol ayant été en contact avec l'eau.

Une demande incompatible avec celle des géochimistes. Ces derniers cherchent avant tout à comprendre la genèse de la planète et à établir un parallèle entre Mars et la Terre. Leur intérêt se porte donc sur des roches volcaniques en provenance du manteau, des basaltes par exemple, qu'ils pourraient dater *via* la désintégration de leurs éléments radioactifs. Ils aimeraient en particulier dater les dernières éruptions volcaniques. *"Les sédiments sont constitués de dépôts de provenances diverses, qui ont été altérés, dégradés*, précise Jean-Louis Birck, de l'Institut de physique du globe. *Il n'est guère facile de les dater de cette manière. Nous fuyons les roches qui se sont trouvées au contact de l'eau."*

Alors, entre volcan ou rivière, que choisir ? *"Une solution de repli serait de recueillir d'éventuels galets drainés par les rivières. La surface de ces galets aura probablement été altérée par l'eau mais on peut espérer que leur cœur soit intact"*, reprend Jean-Louis Birck.

Les spécialistes de l'atmosphère, quant à eux, rêvent d'un échantillon de la calotte polaire. En effet, au fur et à mesure de sa formation, la glace emprisonne des bulles de gaz, dont la composition chimique est la même que celle de l'atmosphère de l'époque. De quoi ainsi retracer l'évolution du cocon gazeux de la planète rouge. Mais ne rêvons pas : les robots des prochaines missions, utilisant leurs panneaux solaires pour faire le plein d'énergie, ne pourront fonctionner qu'à des latitudes équatoriales, là où l'ensoleillement est maximal. Quant à prélever un flacon d'air au-dessus des calottes, une montgolfière ferait l'affaire, *"mais celle-ci n'est pas prévue avant 2005"*, déclare Éric Chassefière, du Laboratoire de météorologie dynamique. Unique consolation : des échantillons de l'atmosphère au-dessus de l'équateur seront prélevés et analysés sur place. Un flacon sera rapporté sur Terre. Seuls les géologues sont prêts à se satisfaire de n'importe quel site et de n'importe quelle roche. Aucun choix n'a encore été arrêté pour 2005 mais les exobiologistes sont donnés gagnants.

Azar Khalatbari




Photos Nasa

## L'Europe hors jeu ?

L'Europe restera-t-elle dans la course vers Mars ? Début décembre, la question restait ouverte. Tout le monde à l'ESA semblait d'accord pour soutenir Mars Express. Plus question d'unanimité, en revanche, pour donner aux budgets scientifiques de l'agence européenne le coup de pouce sans lequel cette mission était quasiment condamnée (voir Actualité page 25).
Mars Express doit être lancée en juin 2003. À bord, une caméra à très haute résolution, un instrument de cartographie minéralogique de la surface et un laser capable de sonder le sol jusqu'à plusieurs centaines de mètres de profondeur. À quoi s'ajouterait un atterrisseur, Beagle 2, pour des expériences d'exobiologie. Autre vocation de Mars Express : servir de relais aux missions de la Nasa en 2005 et au-delà. Coût : 980 millions de francs. La moins chère des missions martiennes, jure-t-on à l'ESA.

Jean-Pierre Defait

Photos Nasa

tion américaine, qui rentrera dans l'atmosphère terrestre avec les précieux cailloux.

L'autre pièce maîtresse de la mission sera constituée d'un atterrisseur de 1,7 tonne, de son robot mobile et de sa petite fusée MAV, tous deux de fabrication américaine. Le principe est en effet de refaire en 2005 ce qui aura déjà été testé en 2003, à savoir une nouvelle collecte d'échantillons. Une deuxième petite capsule sera donc expédiée en orbite martienne. Ce sera une garantie contre le risque de tout perdre si un incident devait se produire lors de la mission de 2003. Mais ce n'est pas tout. Le choix d'Ariane 5 autorisant des largesses, il restait de la place pour loger un paquet de quatre mini-stations d'une cinquantaine de kilos chacune. Dérivées de la capsule européenne Huygens qui fait route actuellement vers Saturne avec la mission Cassini, ces mini-stations devraient procéder notamment à des sondages sismiques, à l'image de ce qui se fait pour la recherche pétrolière. On peut en attendre des informations inédites sur la structure interne de Mars et sur la présence éventuelle d'eau ou de glace dans son sous-sol.

Dans le même esprit, les Français ont insisté pour que l'atterrisseur principal ait la capacité d'analyser sur place une partie des échantillons récoltés. *"Ce sera une sécurité en cas d'échec du retour d'échantillons,* explique Christophe Sotin. *Mais surtout, nous pourrons ainsi mieux sélectionner les roches à rapporter en tenant compte des données recueillies par les orbiteurs des missions précédentes."* Enfin, ultime profit tiré de la puissance de la nouvelle fusée Ariane 5, l'atterrisseur devrait être équipé d'un dispositif de carottage capable de forer jusqu'à 2 m dans le sol. Cet instrument, dont l'agence spatiale italienne assurera la réalisation, pourrait fournir des indications intéressantes sur d'éventuelles traces de vie (fossiles ou non) susceptibles d'avoir échappé à la destruction par l'oxydation qui sévit à la surface.

On est donc loin du schéma d'origine où les récoltes d'échantillons débutaient dès 2001 et 2003. Un robot était chargé, à cha-

## Des échantillons sous haute protection

Les échantillons martiens ont déjà leurs opposants. Des citoyens américains, inquiets des risques de pollution bactérienne que pourrait provoquer leur présence sur notre planète, se sont organisés en lobby afin de s'opposer à leur retour. Habituée à ce genre de pression, la Nasa a prévu dans le financement de son programme martien une ligne budgétaire pour payer… ses avocats. Au-delà de l'anecdote, ce risque n'est pas pris à la légère et l'agence spatiale s'est entourée d'un luxe de précautions.
Ainsi, la trajectoire de retour de la sonde la fait passer très au large de notre planète. C'est seulement lorsque les instruments de bord auront vérifié l'étanchéité du conteneur et l'absence de pollution bactérienne à bord que sa course sera infléchie sur une orbite de rentrée dans l'atmosphère terrestre.
Une fois la capsule larguée, la sonde elle-même sera renvoyée sur une orbite solaire.
Il a même été envisagé une stérilisation des échantillons par chauffage à 2 000 °C ou par irradiation gamma.
Un tel traitement ayant toute chance de réduire sérieusement leur intérêt scientifique, cette solution sera sans doute évitée.

Dès leur arrivée, les roches martiennes seront, en tout cas, placées en quarantaine dans un laboratoire analogue à ceux où sont manipulés les virus dangereux. Seule une équipe de chercheurs triés sur le volet y aura accès. Après cette période, dont la durée n'est pas définie mais qui pourrait atteindre un an selon Francis Rocard, ingénieur au Cnes, les précieux cailloux seront examinés plus librement.
Le Cnes a obtenu de la Nasa la promesse qu'il n'y aurait pas de quotas et que les Français auraient accès aux échantillons dans les mêmes conditions que leurs confrères américains.
Les chercheurs français aimeraient, en outre, être certains que quelques-uns d'entre eux feront partie de la "première équipe", qui, forcément, publiera la première étude sur ces matériaux inédits. Certains ont même suggéré qu'un laboratoire de quarantaine soit construit sur le territoire français — pour héberger les poussières, par exemple, alors que les roches resteraient aux États-Unis. Une option qui, dans l'immédiat, précise Francis Rocard, *"a été à peine abordée avec les Américains et n'a pas encore reçu l'aval du Cnes."*

Jean-Paul Dufour

the south polar cap. These formations can be traced for hundreds of kilometres and scientists believe they are made of dust and ice, laid down in layers as periods of cold alternated with warmer conditions. A record of the Martian climate may be written in the geology of the area in the same way that the climate record on Earth is reflected in ocean sediments, ice cores and tree rings.

In May 1999, MVACS will land at a latitude of 72° South, at the edge of the southern polar cap. It will study these strange layers, searching for carbonates and ice in the soil. In addition, it will monitor the seasonal $CO_2$ and water content of the atmosphere.

NASA/Science Photo Library

**Extinct: could Mars have been home to life?**

Several cameras on board MVACS will provide much of the data. First, a small descent imager will take photographs as the craft comes in to land. A stereo camera, built at the University of Arizona in Tucson and similar in design to the one carried by Pathfinder now on the Martian surface, will survey the landing site and monitor weather. MVACS also carries another camera mounted on the end of its robot arm. This will take close-up images of the soil and its layering.

The robot arm will also place samples of Martian soil in a small oven known as the Thermal and Evolved Gas Analyzer (TEGA)—a pair of small metal tubes wrapped in platinum wire heaters. The sample occupies one of the tubes, which is heated at a constant rate, along with the other, empty tube. The instrument monitors the temperature of the tubes: any deviation between them will indicate that a phase change is taking place in the sample, the melting of ice, for example, or a carbonate rock decomposing.

Any gases given off by the sample will be flushed through a laser spectrometer. This contains two tunable laser diodes, which emit infrared light over a small range of wavelengths according to the amount of current passed through them. Since gases such as water vapour and $CO_2$ absorb infrared light at specific frequencies it will be possible to measure how much of each is present. "One of the big mysteries of Mars is where is all the water and $CO_2$. TEGA may allow us to see if the soil can be where all the water and $CO_2$ is hiding," says Bill Boynton, a planetary scientist at the University of Arizona who leads the TEGA team.

Spotting oxygen is important too. Much of the planet's water may have been broken down into hydrogen and oxygen by sunlight. The hydrogen would have escaped into space, but the heavier and more reactive oxygen atoms may have been absorbed by the soil. There is some evidence for this already. The Viking landers found that the soil gave off $CO_2$ when nutrients were added. This could indicate life, but Viking also discovered that no organic molecules were present, and life without organic compounds seems unlikely. An alternative explanation is that Martian soil contains a highly reactive oxidising agent—

**'IN 1999, A NASA SPACECRAFT WILL LAND AT THE EDGE OF THE SOUTH POLE TO STUDY THE STRANGE LAYERED TERRAIN'**

something you might expect if it had reacted with atmospheric oxygen in the past. An oxidising soil would decompose nutrients and would destroy any other organic compounds. However, the story may be different beneath the surface, out of reach of an oxygen-rich atmosphere. If TEGA finds no oxidising agents beneath the surface, says Boynton, this might suggest that organic molecules or even microbial life could survive there.

## Weather eye

The lander will provide detailed weather reports. As well as pressure, temperature and wind speed sensors, the lander has a laser spectrometer to determine the composition of the atmosphere by measuring the amount of light it reflects and absorbs. One important measurement will be which isotopes of carbon, hydrogen and oxygen are present in $CO_2$ and water vapour. Heavier isotopes are less likely to escape into space, so their relative

## A catalogue of disasters

### 10 October 1960

The first probe destined for Mars, the USSR's Mars 1960A, fails to reach Earth orbit, setting the trend for a long series of disastrous missions to the Red Planet. Between 1960 and 1997, 17 out of 27 missions to Mars experience some kind of failure

### 14 July 1965

The American spacecraft Mariner 4 becomes the first to fly past Mars returning 22 close-up photographs

### 24 November 1971

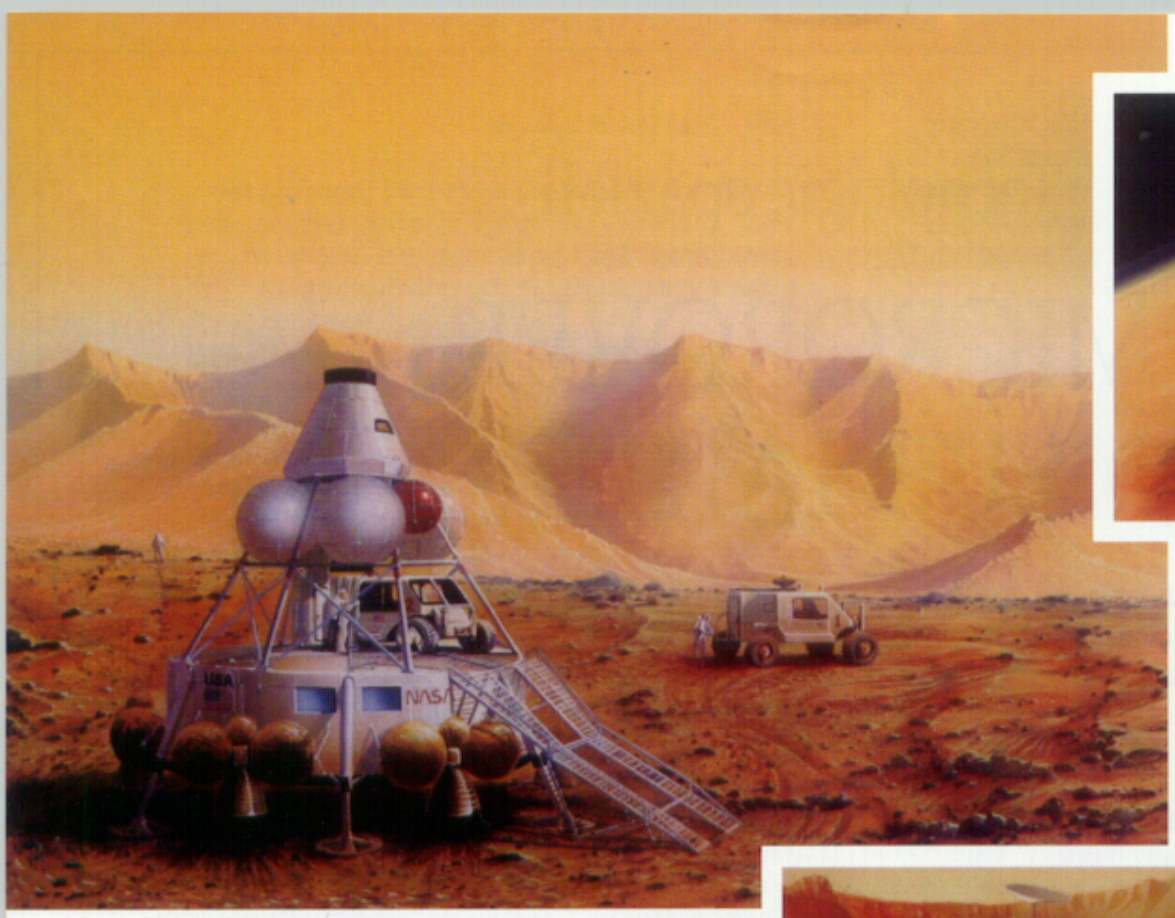
Mariner 9 takes the first high-resolution images of the Martian moons Phobos and Deimos. It also sends back images of rivers and channel-like features on the Martian surface

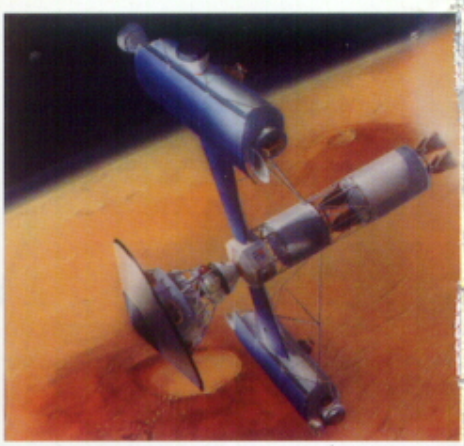
### 27 November 1971

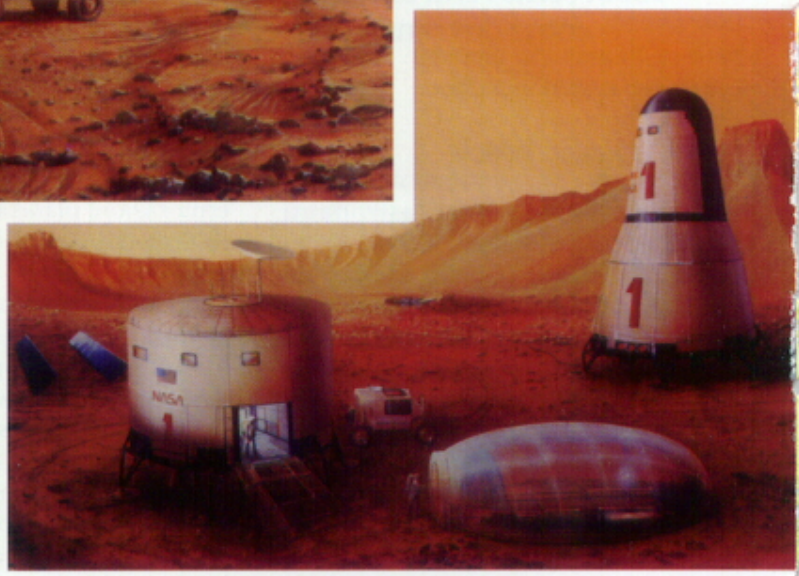
The USSR places the first spacecraft in orbit around Mars. The Mars 2 spacecraft also carries a lander but this crashes when its braking rockets fail

### 2 December 1971

Mars 3 becomes the first spacecraft to make a soft landing on Mars. Unfortunately, it falls silent after only 20 seconds






**Profilo di una missione**

*Questo potrebbe essere lo schema della prima missione esplorativa umana su Marte. Sei astronauti arriveranno in orbita attorno al pianeta in un «veicolo di trasferimento»* ***(in alto a destra)****. Da questo si distaccherà un «Lander» che porterà tre di essi sulla superficie; gli astronauti avranno a disposizione due veicoli per le escursioni esplorative. Il passo successivo sarà l'impianto di una base permanente* ***(a destra)****. Ma questa dovrà essere preceduta dalla realizzazione di una base simile sulla Luna.*

ne) e proteggere gli astronauti. Tutto questo significa peso e un missile ha una efficienza molto bassa: solo il 5% del peso al decollo di un Saturno 5 arrivava in orbita terrestre e circa l'1% in orbita lunare. E queste proporzioni sono valide sempre, quindi anche se si vuole mandare una sonda automatica a esplorare un altro pianeta. Portare quindi un veicolo automatico simile all'auto lunare, su Marte o su un asteroide, richiede non solo un vettore di dimensioni colossali ma soprattutto uno sforzo finanziario ragguardevole.

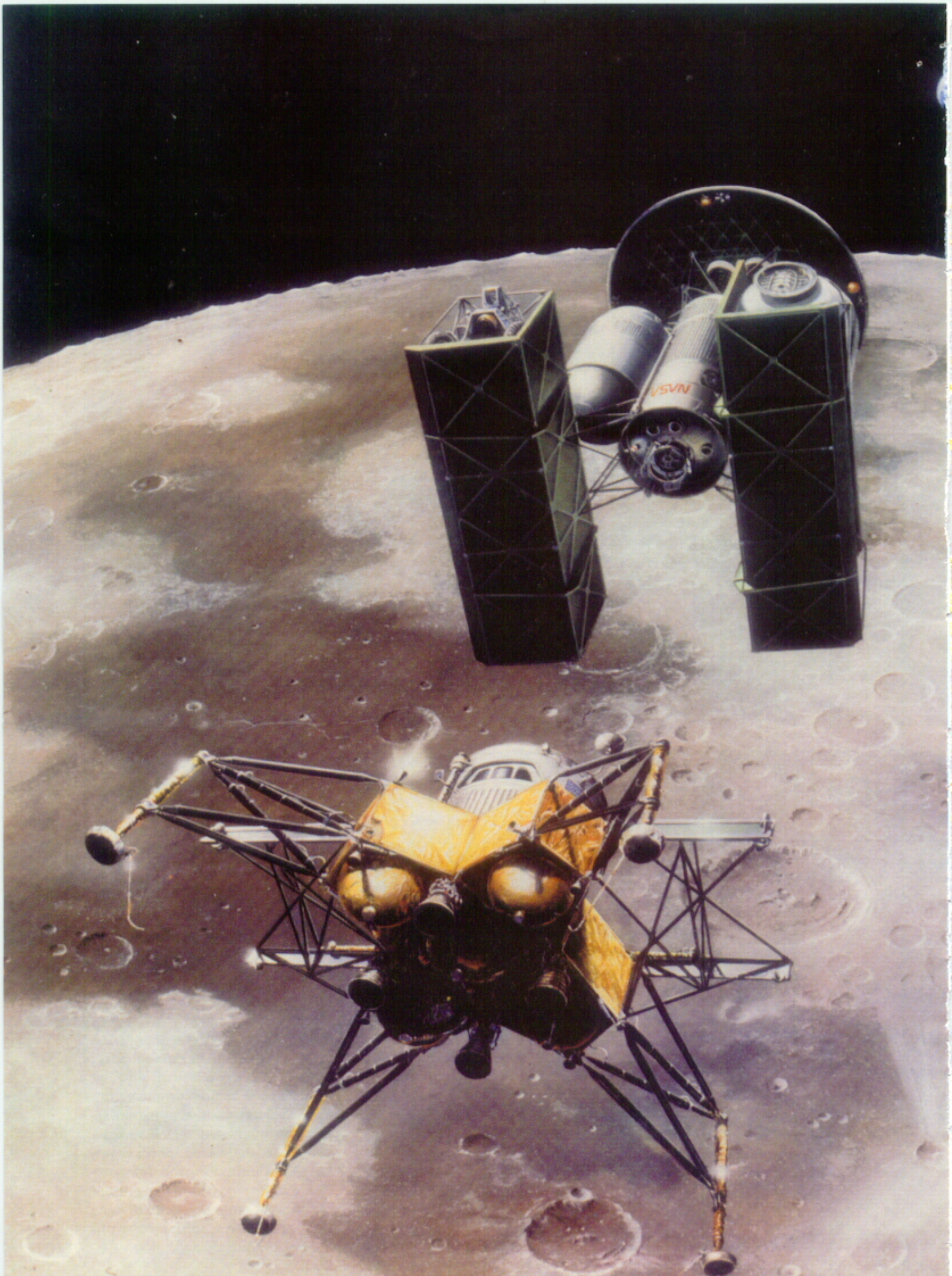
Fin dagli albori delle attività spaziali si è sempre ritenuto indispensabile procedere per gradi: l'esplorazione umana di un pianeta deve essere preceduta da una ricognizione satellitare e dall'invio di sonde automatiche in grado di spostarsi autonomamente sul suolo del pianeta. La distanza e quindi la difficoltà delle comunicazioni, o quanto meno il tempo necessario affinché i segnali arrivassero sulla Terra e potessero essere ritrasmessi dei comandi, suggerivano veicoli con un certo grado di autonomia, quindi di intelligenza artificiale. Ma si finiva per scontrarsi con i pesi e le dimensioni e pur tra mille difficoltà Marsokhod, un veicolo progettato dai russi per una missione esplorativa su Marte da realizzarsi forse nel 1996, pesa 100 kg. Sei ruote coniche, una certa autonomia decisionale e un generatore a radioisotopi per l'alimentazione elettrica, rappresenta la soluzione conservativa al problema dell'esplorazione planetaria.

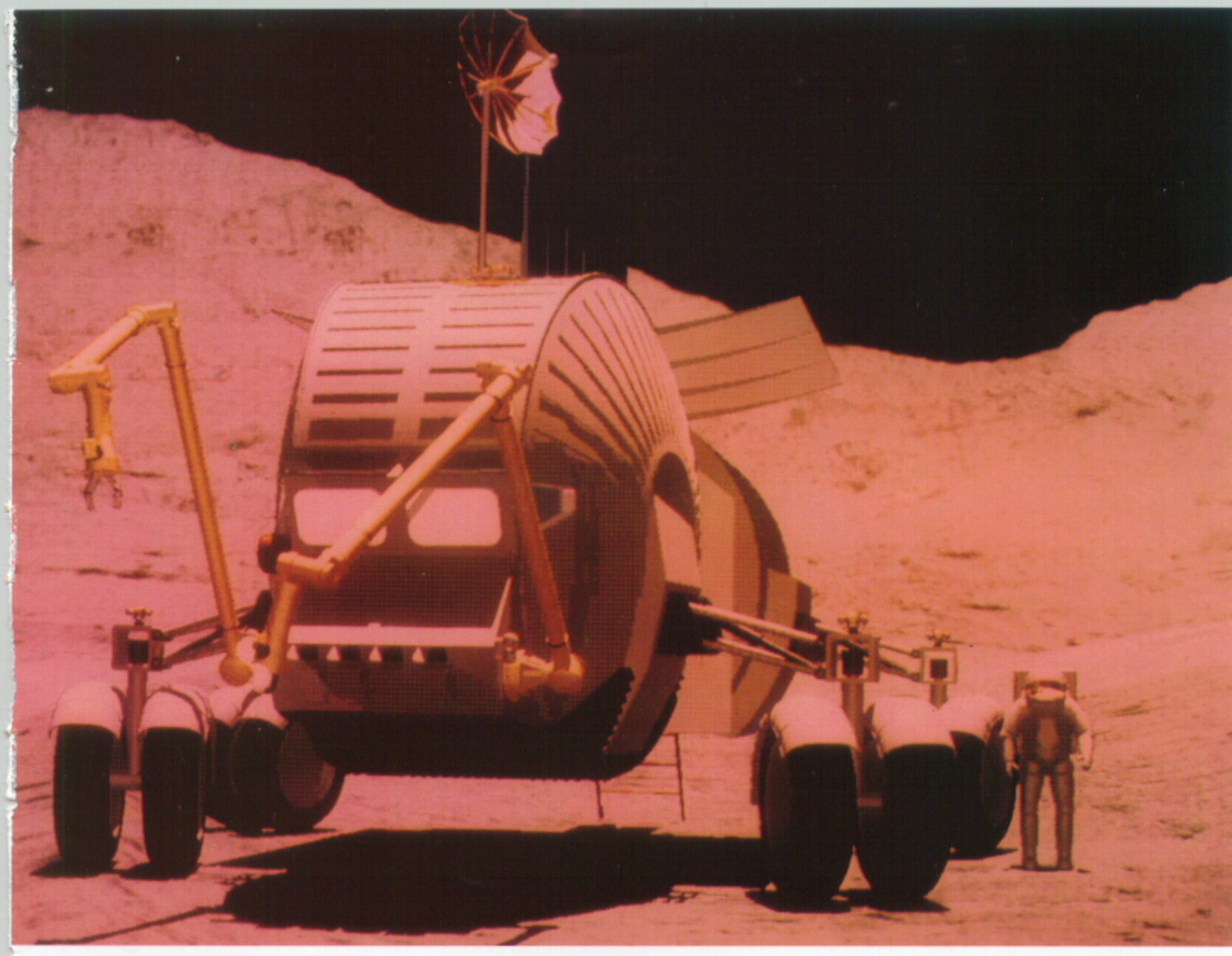
Ma spesso esistono soluzioni migliori di quelle ottimali, e sono quelle dovute ad approcci cosiddetti innovativi.

Recentemente sia i francesi del CNES, l'agenzia spaziale francese, che gli scienziati del JPL, il Jet Propulsion Laboratory dell'Istituto di Tecnologia della California, hanno proposto un modo completamente nuovo di risolvere il problema. Al JPL hanno sviluppato Rocky 4, 7 kg di peso, 6 ruote e un costo di solo 2 milioni di dollari contro i 20 milioni del sovietico Marsakhod.

Il CNES invece ha allo studio un VAP, veicolo automatico planetario, caratterizzato da un telaio telescopico per adattarsi agli ostacoli. Fin dal 1989 stanno studiando dei RISP, robot d'intervento su siti planetari, con l'idea di fondo, comune anche ai progetti del JPL, di realizzare un veicolo automatico, semplice nelle strutture meccaniche, flessibile nell'uso, con una elevata autonomia grazie ad algoritmi inferenziali e adattativi che utilizzano le tecniche dell'intelligenza artificiale per quanto riguarda la visione e quindi il riconoscimento degli ostacoli.

Lo scopo è quello di svolgere ricognizioni ed esplorazioni planetarie, raccogliendo e analizzando campioni e svolgendo profili di misure.


VSVN

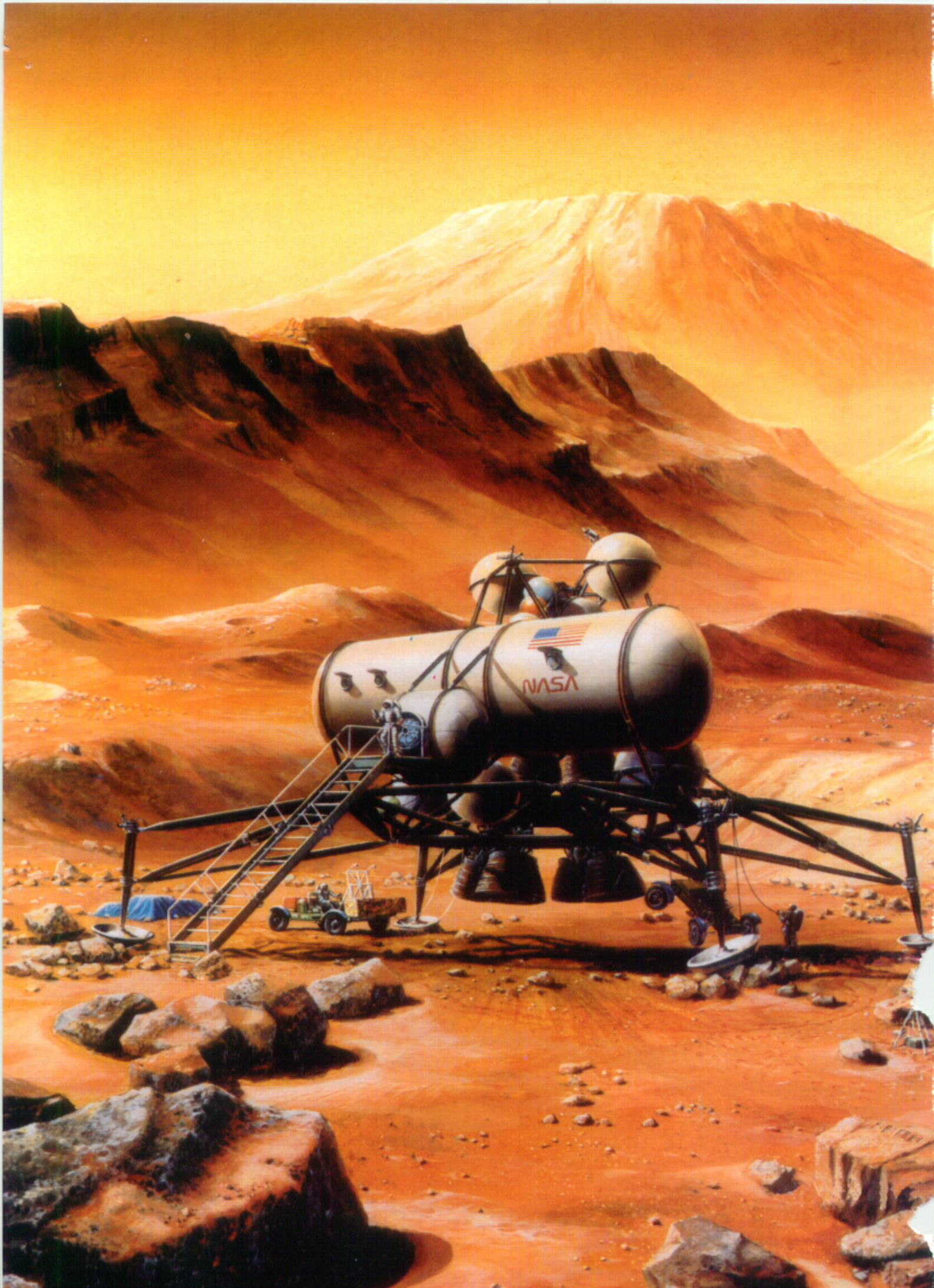


## Rover planetario

***Qui sopra:*** *la rappresentazione di un veicolo per l'esplorazione planetaria, progettato negli Stati Uniti. Verrà sperimentato sulla Luna, e in seguito potrà servire gli astronauti su Marte.*

***Qui accanto:*** *esiste già una simulazione di quello che potrà essere il suo «posto di guida». La sua complessità è paragonabile a quella del cruscotto dello Shuttle.*

Il MIT, l'Istituto di Tecnologia del Massachussetts, va anche oltre: perché limitarsi a veicoli da 7 kg realizzati con tecnologie ancora domestiche? Passiamo alle micromacchine e realizziamo veicoli su scala molecolare del peso di pochi grammi. Quest'ultima è probabilmente solo una provocazione per attirare l'attenzione sulle potenzialità delle micromacchine e sulle loro applicazioni potenziali nella manuten-


NASA

## UN PO' D'ITALIA SUL PIANETA ROSSO

*Le difficoltà finanziarie e politiche dei programmi spaziali sovietici hanno favorito la collaborazione di imprese italiane alla missione MARS 94, il cui obiettivo è esplorare il "pianeta rosso".*

*Il progetto da lanciare alla fine del '94 è quello di una scuola automatica che atterrerebbe in uno dei "mari" marziani, e da cui si distaccherebbe un veicolo mobile che esplorerebbe un ampio territorio.*

*Nello sviluppo di questo MARS Rover sono state coinvolte numerose ditte italiane.*

*FIAT Spazio è la capocommessa responsabile dell'intero progetto, che vede l'Istituto di Astrofisica dell'Accademia Sovietica delle Scienze, il CNR e l'Università di Perugia responsabili scientifici della missione.*

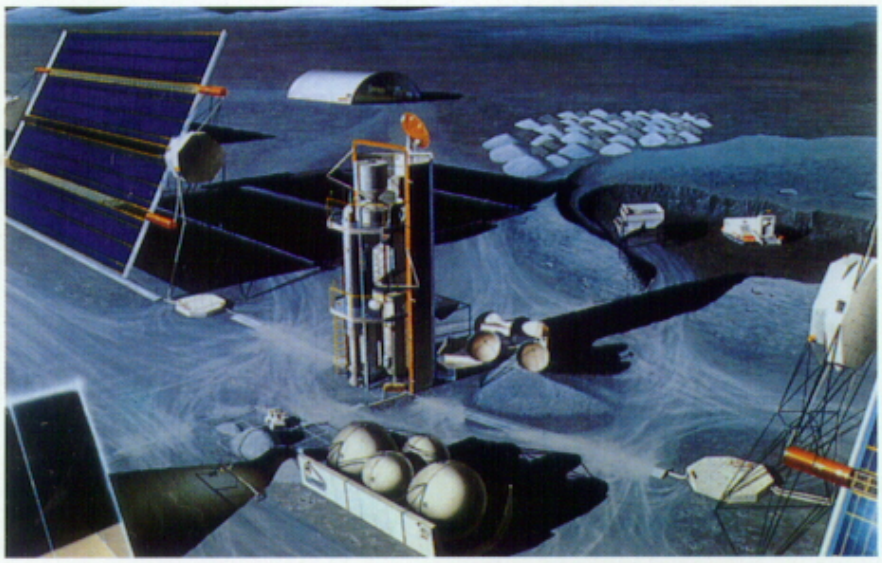
*Alla Telerobot del gruppo Ansaldo - Elsag, alla Tecnospazio (un consorzio creato dalla COMAC del gruppo FIAT e della FIAR dell'IRI - Finmeccanica) e alla sovietica LAVOTCHKIN è assegnato lo sviluppo dei sottosistemi.*

*Un prototipo è stato oggetto di una intensa campagna di prova la scorsa estate nella Valle della Morte in California, dove l'asprezza del territorio e la forte escursione termica notturna e diurna sono ben rappresentative delle difficoltà della missione marziana.*

*La difficoltà maggiore per il progetto del MARS Rover riguarda la sua autonomia.*

*Un compromesso opportuno tra carico utile trasportato, autonomia e capacità robotiche consentirà l'ottimizzazione dei risultati per il profilo di missione previsto.*

*Non è un caso che il gruppo FIAT sia interessato a questo veicolo proprio per la simbiosi bidirezionale che si può instaurare tra discipline di punta, quali l'esplorazione spaziale, e le produzioni industriali di massa, quale quella automobilistica.* ■



**Dalla Luna a Marte**

***A sinistra:*** *un «Veicolo di trasferimento lunare» si distacca dall'astronave-madre per scendere sul nostro satellite. Veicoli di questo tipo serviranno a portare sulla Luna le strutture necessarie per impiantarsi una base stabile, premessa alla realizzazione di una base analoga su Marte. I veicoli non partiranno dal suolo terrestre, ma dall'orbita, avendo come punto di riferimento una base spaziale permanente, successiva alla progettata stazione Freedom che dovrebbe essere montata in orbita nei prossimi anni.*

***Qui sopra:*** *si stanno già progettando i diversi possibili insediamenti lunari. La base raffigurata nel disegno sfrutta come fonte d'energia un grande specchio solare. L'impianto a torre al suo centro serve a estrarre ossigeno dalle rocce lunari.*

zione industriale e nella biologia, ma resta l'interesse per l'approccio innovativo. Invece di mandare veicoli grandi come trattori, e del peso di alcuni quintali che richiedono vettori colossali, miniaturizziamo il tutto e diversifichiamo.

Non più una singola missione omnicomprensiva con satelliti o sonde cariche all'inverosimile di strumenti, con il rischio come spesso è accaduto che una saldatura di poche lire mal realizzata blocchi una intera missione. Invece si tratta di realizzare molte missioni, ognuna leggermente diversa dalle altre, tutte condotte con vettori piccoli, micromacchine, strumentazioni semplici, per lo più a stato solido, figli della rivoluzione informatica. Se qualcuna si guasta, l'inconveniente non si riflette sulle altre missioni, e complessivamente il programma fornisce comunque risultati. È il concetto della ridondanza applicata non solo alla componentistica ma proprio alla pianificazione delle missioni. E le ripercussioni per le ricadute tecnologiche non sono indifferenti. Un'auto lunare da 200 kg non trova facilmente applicazioni terrestri ma un piccolo robot semovente del peso di pochi chilogrammi, con una telecamera, una sua capacità di elaborazione d'immagine e dati può servire per la manutenzione di impianti nucleari o per il trasporto di sostanze pericolose all'interno di un laboratorio o di un'azienda farmaceutica, mentre il suo sviluppo richiede know-how le cui ricadute terrestri sono innumerevoli.

Naturalmente tutto questo deve essere economico, perché il Rover lunare è stato il veicolo più caro mai costruito dall'uomo. Aereo e treno costano circa 100 lire al chilometro per passeggero, il Saturno 5 sul percorso Terra-Luna costava 5 milioni al chilometro per passeggero, mentre il Rover, costato l'equivalente di 60 miliardi di oggi e utilizzato per un totale di 28 km da due astronauti, ha avuto un costo di esercizio di circa un miliardo a chilometro per passeggero. Alle nuove RAMES, robotica autonoma mobile per l'esplorazione planetaria, si chiede innanzitutto di essere più economiche.

Tecnologie spaziali

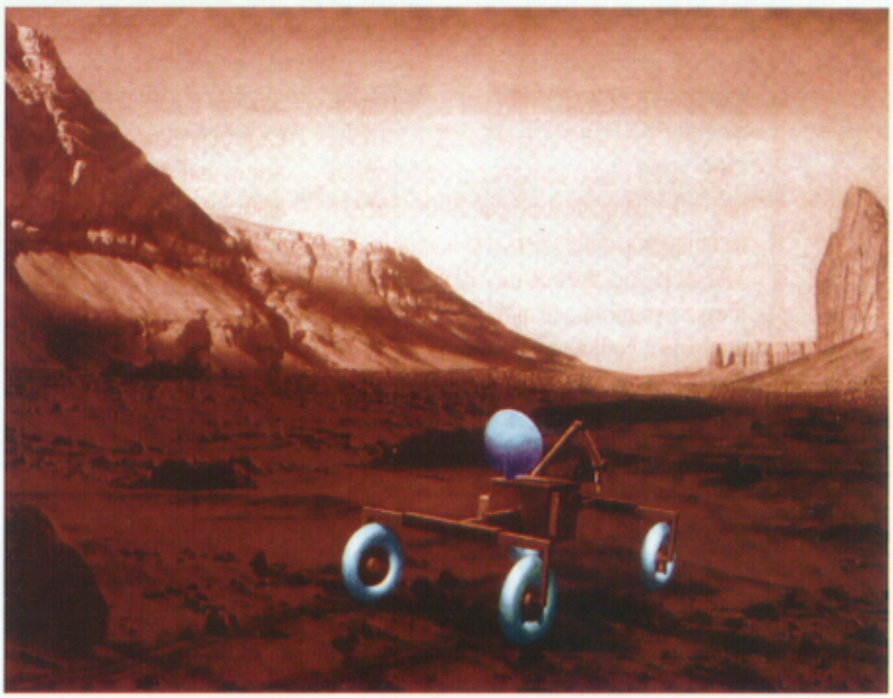
# MICROROVER SU MARTE

Andranno in avanscoperta sul Pianeta Rosso per preparare l'arrivo dell'uomo. Piccoli robot semoventi dotati di Intelligenza Artificiale studieranno l'ambiente per farci capire come dovranno essere realizzate le prime basi abitabili sulla Luna e su Marte.

DI CLAUDIO BORGONOVI

All'inizio degli anni 70, gli astronauti del Programma Apollo portarono sulla Luna tre esemplari di vettura lunare, il *Rover*. Costruito dalla Boeing e dalla General Motors, era un'auto elettrica del peso di circa 200 kg, con un'autonomia di 100 km alla velocità di 14 km/h e in grado di trasportare circa 500 kg.
Quattro ruote, ognuna dotata di un motore da un quarto di cavallo e una potenza complessiva pari a un ventesimo di una utilitaria terrestre, questa vettura ha rappresentato per almeno trent'anni l'idea di base per un veicolo automatico in grado di svolgere esplorazioni planetarie.
Se i satelliti per telecomunicazioni, per telerilevamento e per meteorologia rappresentano le attività spaziali più redditizie, l'esplorazione soprattutto di altri pianeti incarna il mito e il fascino dello spazio.
Da parecchi anni sia gli statunitensi che i sovietici stanno progettando una missione umana su Marte e l'esplorazione di altri pianeti e asteroidi. Le difficoltà di bilancio e soprattutto i quasi tre anni di viaggio richiesti da una missione su Marte, rappresentano ostacoli non trascurabili.
I rischi della missione stessa possono essere ridotti tramite una accurata pianificazione, ma ogni volta che si programmano esplorazioni con equipaggio ci si chiede se sia veramente necessario inviare astronauti a milioni di chilometri di distanza solo per prendere qualche campione e qualche foto. A parte le dichiarazioni sul ruolo simbolico dell'astronauta esploratore, indubbiamente solo l'uomo può affrontare rapidamente e con successo situazioni d'emergenza, almeno se queste rientrano nel suo addestramento e non sono troppo gravi.
Ma la presenza dell'uomo a bordo di un'astronave richiede tutta una serie di dispositivi per garantire condizioni simili a quelle terrestri (aria, calore, luce, acqua, pressio-

## Remoti avamposti

***A sinistra:*** *un «avamposto» sulla superficie marziana, secondo uno dei diversi progetti che attualmente sta valutando la NASA. Potrebbe essere inviato sul Pianeta Rosso entro i primi due decenni del prossimo secolo, per condurre ricerche sul pianeta del Sistema Solare più simile alla nostra Terra.*

***A destra:*** *il suo arrivo sarà preceduto da quello di uno strumento simile a quello qui raffigurato. Si tratta di un VAP (Veicolo Automatico Planetario) che dovrà esplorare palmo a palmo la zona prescelta per l'atterraggio del laboratorio abitato da esseri umani.*